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WINTER SECTIONAL MEETING

AN excellent program has been prepared for the Winter Sectional Meeting at Buffalo, January 21 and 22, 1926. The sectional meetings of the A. S. S. T. are gaining in importance and attendance from time to time and the Buffalo meeting gives every evidence of achieving and surpassing the previous meetings. The members will begin to gather on Wednesday, 20, inasmuch as on that day the newly elected national officers will hold the first meeting of the year at the Statler Hotel, for the transaction of important business. On the same date, the Publication Committee of TRANSACTIONS, under the direction of Professor Herbert M. Boylston of Case School of Applied Science, will hold a meeting at Hotel Statler, for consideration of publication problems and the determination of policy. At 6:30 P. M. that evening, there will be an innovation in the sectional meeting activities in the Early Bird's Dinner, to which all of the members of the Society are invited and all of the members of the Buffalo chapter will have dinner with these in attendance from out of town. After dinner the party will attend the theatre.

On Thursday morning the technical sessions will begin. The afternoon will be devoted to a plant inspection. At 6:30 P. M. that evening in the Ball Room at Hotel Statler, a banquet will be held, at which time a number of interesting addresses will be made by invited guests. On Friday there will be two technical sessions and one plant inspection. The technical sessions will probably be held in the morning and the evening. Friday evening will mark the official close of the sectional meeting, yet on Saturday a trip has been planned to Niagara Falls for the benefit of those who have not had the opportunity to visit the Falls before or desire to renew their vision of it under winter conditions.

The following papers have been prepared and will be presented at this sectional meeting: *Testing of Automobile Sheet Steel,* by Dr. G. L. Kelley of the Edward G. Budd Manufacturing Co.; *The Laboratory as a Factor in the Inspection of Alloy and Tool Steels,* by W. H. Wills, Jr., metallurgist, Atlas Alloy Steel Corp.; a report supplementing work relating to the *Effect of Size and Shape on the Hardening of Steels,* by H. J. French and O. Z. Klopsch, Bureau of Standards; *Electric Steel Melting from the Metallurgist's Viewpoint,* by Dr. Birger Egeberg, Halcomb Steel Co.; *On the Nature of Alloys of Iron and Chromium,* by E. C. Bain, Union Carbide and Carbon Research Laboratories; *Influence of Changes in Carbide Concentration on X-Ray Structure of Some Pure Iron-Carbon Alloys,* by Dr. W. L. Fink, Aluminum Company of America.

Chairman G. J. Armstrong of the Buffalo chapter has appointed the following committees: *Publicity Committee,* chairman, B. L. McCarthy; O. W. Mueller, F. G. Moore; *Finance Committee,* chairman, B. Clements; B. D. Walls; *Dinner Committee,* chairman, G. J. Armstrong; W. J. Gamble; *Entertainment and Arrangements Committee,* chairman, O. W. Mueller; F. B. Lounsberry, W. H. Blocksidge, D. Bell, F. G. Brost, C. R. Pafenbach, F. C. Burkhardt, R. E. Sherlock; *Registration Committee,* chairman, B. L. McCarthy; W. S. Miller and F. L. Weaver.

Hotel Reservations

The Statler Hotel will be the official headquarters and all technical sessions will be held at that hotel. Members and guests should make their reservations directly with the hotel management, stating the time of arrival, price of accommodations desired and request an acknowledgment of the reservation. The rates are as follows:

Single rooms—with both shower and tub, $3.50, $4.00, $4.50 $5.00, $5.50, $6.00, $7.00.

Double rooms—(For two)—one double bed. With both shower and tub, $5.50, $6.00, $6.50, $7.00, $7.50, $8.00, $9.00.

Twin-bed rooms—(For one or two). With both shower and tub, $6.50, $7.00, $7.50, $8.00, $8.50, $9.00, $10.00, $12.00.

Every room has its own private bath, circulating ice water and other unusual conveniences. A daily paper is placed under the door every morning.

WORTHY CONTRIBUTIONS TO METALLURGY

THIS issue of TRANACTIONS contains several important contributions to the science of metallurgy. In one of the papers, by H. J. French and T. G. Digges entitled "Experiments with Nickel, Tantalum, Cobalt and Molybdenum in High Speed Steels" the authors have described the results of their researches in the alloying of these elements in high speed steel. This papr, together with the discussion, presents a valuable addition to the science.

A second paper by Dr. D. J. McAdam, Jr., entitled "Effect of Cold Working on Endurance and Other Properties of Metals," Part I and Part II, is a distinct contribution to the science. Dr. McAdam has been conducting extensive researches on the subject of fatigue and has published a number of his papers in TRANSACTIONS. The paper by French and Digges and also that by Dr. McAdam were presented at the Cleveland Convention of the society.

A third paper entitled "Thermal Disturbances and Recrystallization in Cold-Worked Steels" by Dr. V. N. Krivobok is likewise a valuable addition to our knowledge of metallurgy and crystallography. Dr. Krivobok has been closely associated with Dr. Albert Sauveur and has had the privilege of studying these problems with Dr. Sauveur and later at Carnegie Institute of Technology.

THE NEW YORK CHAPTER MEETING

THAT steel treaters are eagerly in quest of practical information was strikingly shown at the November meeting of the New York chapter last week, with its unique symposium on alloy steels as reported on other pages. The attendance was the largest since the organization of the chapter. While much of the information given out by the six experts—all New York men but one—was familiar to some of those present, even the most experienced was amply rewarded. Similar monthly meetings are held in a chain of cities, stretching from coast to coast, the sum total of the movement, both in attendance and in metallurgical output, making it fairly phenomenal. These chapter activities, in view of their informality and the practical character of the addresses, have been invaluable to the younger practitioners. There is no mystery, therefore, about the enthusiasm that has borne the American Society for Steel Treating from one success to a still greater one in successive annual conventions.—*Iron Age.*

STEEL MELTING SESSION

ON Tuesday morning, September 15, there assembled in the Ball Room of the Cleveland Hotel about 500 members of the society to hear presented and discussed several papers dealing with the relative merits of steelmaking by the acid and basic open hearth processes and the electric furnace process. Dr. J. A. Mathews, vice-president of Crucible Steel Company of America, presided.

The four papers comprising this session are printed in full in this issue of TRANSACTIONS, together with the discussions, both written and oral, which followed their presentation. This session really marked the first effort of the society on this important subject.

In discussing the subject of the "Proportion of Heat Treated Steel to Total Production," C. J. Stark, president of Penton Publishing Company, states that the automobile industry has proved itself the greatest patron of heat treatment of steel as it also has of alloy steel. He points out that last year this industry consumed approximately 3,200,000 gross tons of rolled steel and of this quantity probably 15 to 20 per cent was of alloy quality. On the general basis, estimated, he continues, the automobile industry today is using 50 to 60 per cent of all the commercial alloy steel produced. He directs attention to the fact that the railroads are backward in adopting heat treating of their material largely because of the need of a scientific knowledge and skilled labor to properly meet their requirements. In closing he says that from 3,000,000 to 3,500,000 tons of steel are being scientificially treated annually to serve various economic or mechanical purposes.

The second paper was presented by Radclyffe Furness, superintendent of the melting and forging departments of the Midvale Co., Nicetown, Philadelphia. In his paper entitled "Acid Open Hearth Melting Practice" the author emphasizes the importance of the ore addition, pointing out that the greatest care should be used to add the exact amount at the proper rate in order to bring the carbon to the desired point when all the ore has been reduced and the resultant gas boiled off. The characteristics of the process as well as the reactions and the composition of the slags are fully treated. The details of charge, melting and pouring temperatures are discussed. Reasons for the superiority of acid over basic steel

are also given with emphasis on the importance of the proper "conditioning" of both, stating that this has a great influence on the defects which may appear in the finished product.

The third paper was presented by E. A. Whitworth, Gathmann Engineering Company of Baltimore, entitled "Basic Open Hearth Practice." In this paper the author states that in melting alloy steels and high-grade carbon forging steels for a charge of 210,000 pounds, the limestone charge should be at least 21,000 pounds, the scrap charge 60 per cent of clean, and as much heavy scrap as is available, and 40 per cent of hot metal. With pig iron of 0.90 to 1.00 per cent silica and 1.75 per cent manganese and a fairly sharp working furnace using oil for fuel, the heat should melt close enough to the desired tapping point in carbon so that it will not be necessary to use an excessive amount of ore for recarburization.

The author states that there should be no addition of ore for at least 30 minutes to an hour before tapping so as to insure the absence of iron oxide in the bath. After the bath has been worked down in carbon to the "go-ahead" point and the slag is "shaped up" and the temperature about what is wanted by the melter, the addition of about 2500 pounds of 10 per cent silicon pig is made to the bath after the final preliminary test is sent to the laboratory for the determination of carbon, manganese and sulphur. From 20 to 30 minutes are required to get the analysis back to the open hearth, during which time the oxidation of the silicon, rather than carbon, takes place, allowing the melter to figure the bath the same as when the final test was sent to the laboratory. The use of ferrosilicon at this point is beneficial as a deoxidizer because its oxide seeks out the manganese oxide suspended in the metal, forming manganese silicate, which is easily fusible at pouring temperature, causing it to coalesce and go into the slag readily while the manganese oxide is likely to remain suspended, causing defects in the metal when cold. The silicon also reacts with any carbon monoxide or ferrous oxide dissolved in the bath.

The fourth and last paper contributed by F. T. Sisco, metallurgist, air service, War Department, McCook Field, Dayton, Ohio, was presented in abstract by Jerome Strauss, material engineer, Naval Gun Factory, Washington, D. C. This paper is a very capable and valuable contribution to the literature.

The author discusses the outstanding features and advantages

of the electric furnace method of steel production. He gives a description of the three types of electric melting furnaces used in steel production and discusses in detail the process of melting, the chemistry of oxidation, the control of oxidation in melting, slag deoxidation, slagging off, recarburization and many other factors entering the practice of electric furnace steel production.

Considerable valuable and interesting discussion followed the presentation of each paper. Some of the discussion was in the form of written discussion, while a considerable amount was oral discussion. These discussions accompany the papers as published in this issue of TRANSACTIONS.

THIS issue of TRANSACTIONS completes Volume VIII, which covers the period from July, 1925, through December, 1925. Volume IX will include the period from January, 1926, through June, 1926. The index for Volume VIII is now ready and may be secured upon request.

Those desiring to have their loose copies of Volume VIII bound in accordance with the style used in binding Volumes I, II, III, IV, V, VI and VII, may do so by forwarding them to the executive offices of the Society, 4600 Prospect Avenue, Cleveland, together with $2.00, and they will be bound and returned promptly.

Future Meetings

WINTER SECTIONAL MEETING—Hotel Statler, Buffalo, N. Y., January 21, 22 and 23, 1926.

SPRING SECTIONAL MEETING—Hotel Bond, Hartford, Connecticut, May 20 and 21, 1926.

ANNUAL CONVENTION AND EXPOSITION—Municipal Pier, Chicago, Illinois, September 20-24, 1926.

REPORT OF SUB-COMMITTEE ON CARBURIZING GEARS AND OF SUB-COMMITTEE ON CARBURIZING CAMSHAFTS

THE Recommended Practice Committee of the American Society for Steel Treating has recently approved as tentative recommended practices of the Society, two reports, namely, the Recommended Practice for the Carburizing of Gears and the Recommended Practice for the Carburizing and Heat Treatment of Camshafts. The two sub-committees which compiled these reports have spent considerable time and thought on these problems in an endeavor to compile suitable recommended practices covering these two phases of heat treating.

These reports, which follow, will remain tentative for a period of not less than one year and will then be presented to the Board of Directors by the Recommended Practice Committee for adoption as standard recommended practices of the Society. Constructive criticism of these tentative recommended practices is encouraged.

The members composing these two sub-committees were as follows: Sub-committee on Carburizing Gears: chairman, F. C. Raab; members: L. M. Fenner, S. C. Spalding, M. A. Allen, Leon Slade, H. M. Northrup and E. C. Smith. Sub-committee on Carburizing and Heat Treatment of Camshafts: chairman, E. H. Stilwill, members: H. M. Northrup, C. A. Furgason, E. G. Hergenroether, R. J. Giblin, Edmund Blasko, W. H. Graves and F. L. Woodside.

Recommended Practice for the Carburizing and Heat Treatment of Camshafts

General

THIS recommended practice covers the process to be followed in the carburizing and heat treatment of camshafts.

Chemical Composition

The steels listed in Table I may be used for camshafts and this recommended practice is not applicable to steels having any other chemical composition.

Table I

Chemical Composition

Steels	C	Mn	P max.	S max.	Ni
S. A. E. 1015	0.10–0.20	0.30–0.60	0.045	0.05	.....
S. A. E. 1020†	0.15–0.25	0.30–0.60	0.045	0.05	.....
S. A. E. 2320	0.15–0.25	0.50–0.80	0.040	0.045	3.25–3.75
½% Ni	0.10–0.20	0.30–0.60	0.045	0.050	0.50–0.70
S. A. E. 2512	0.17 max.	0.30–0.60	0.040	0.045	4.50–5.25
S. A. E. 3120[1]	0.15–0.25	0.30–0.60	0.040	0.045	1.00–1.50
Ni-Mo[2]	0.10–0.20	0.30–0.50	0.040	0.045	1.25–1.75
S. A. E. 6120[3]	0.15–0.25	0.50–0.80	0.040	0.040	.....
Cr-V†	0.10–0.15[4]	0.30–0.50	0.040	0.040	.....

†These steels are the ones most commonly used for camshafts.
[1]The chromium content for this steel is 0.45 to 0.75 per cent.
[2]The molybdenum content for this steel is 0.20 to 0.30 per cent.
[3]The chromium content for this steel is 0.80 to 1.10 per cent and the vanadium content is 0.15 to 0.20 per cent.
[4]The chromium content for this steel is 0.25 to 0.40 per cent and the vanadium content is 0.15 to 0.20 per cent.

Annealing and Heat Treatment After Forging and Before Machining

For annealing the S. A. E. steels 1015, 1020, 2320, 3120, 6120, and the 0.50 per cent nickel, nickel-molybdenum, and the chromium-vanadium steels, place the steel in the furnace so as to expose maximum surface area. Heat slowly and uniformly to a temperature of 1600 to 1650 degrees Fahr., and cool at a rate to give the desired machinability.

For annealing the 5 per cent nickel steel (S. A. E. 2512), place in furnace so as to expose maximum surface area. Heat slowly and uniformly to 1600 degrees Fahr., and hold at this temperature for about one hour. Cool slowly in furnace to 800 degrees Fahr., and then cool in air.

Before machining hollow camshafts quenching and tempering operations, at the proper temperatures, are advisable to give the desired machinability.

Preparation of Camshafts for Carburizing

Two methods are used for maintaining a camshaft that will straighten without breaking after hardening.

One method consists of copper plating the entire shaft prior to carburizing and removing the copper by grinding or turning from those areas which are to be carburized and hardened.

The second method consists of forging or machining the camshafts somewhat larger with an excess of metal between the cams

and bearings. This excess metal is machined off after carburizing and before hardening.

Carburizing Camshafts

The carburizing operation should be carried out in containers and furnaces of suitable dimension and design to permit uniform heating throughout the charge. The carburizing temperatures for the various steels are given in Table II.

The camshafts should be so packed that the areas to be hardened do not come in contact with each other or with the walls of the containers.

Sufficient compound should be used so that the camshafts are not exposed at any time during the carburizing and cooling operations; after carburizing the camshafts are allowed to cool in the containers.

Case Depth

The time required to attain the depth of case depends upon a number of factors, such as temperature of the furnace at time of loading, rate of heating, type of furnace, thickness of the containers, amount of stock left for grinding, etc. However, the carburizing time and the amount of stock left before grinding should be so regulated that the depth of case after grinding is at least 0.045 of an inch. The hardness of the camshaft should not be below a scleroscope reading of 75.

Heat Treatment of Camshafts after Carburizing

Hardening

The camshafts should be heated uniformly to the temperature given in Table II, and held for complete penetration of heat. The heating medium should be of such a character that no decarburization will take place.

To prevent warpage, the shafts should be arranged properly in the heating medium and quenched either vertically or rolled horizontally into the quenching bath.

Tempering

After quenching, reheat the camshafts in a suitable tempering medium to the temperature given in Table II, and hold at

this temperature for at least one hour to insure complete penetration of heat. The highest temperature that will not affect the hardness should be used.

Table II

Carburizing and Heat Treatments for Camshafts

Steels	Carburizing Temp. Deg. F.	Cool in	Reheat to Deg. F.	Quench in	Tempering Temp. Deg. F.
S. A. E. 1015	1625–1750	box	1425–1450*	water or brine	350–400
S. A. E. 1020	1625–1750	box	1425–1450*	water or brine	350–400
½% Ni	1650–1700	box	1375–1425*	water or oil	250–450
S. A. E. 2320	1575–1625	box	1325–1375*	oil	250–450
S. A. E. 3120	1625–1675	box	1375–2425*	water or oil	250–450
S. A. E. 2512†	1600–1650	box	1350–1400*	oil	250–450
Ni-Mo	1650	box	1475–1525	oil	350
S. A. E. 6120	1675–1725	box	1425–1475*	water or brine	400–450
Cr.-V	1675–1725	box	1425–1475*	water or brine	400–450

*Use lowest possible temperature to produce maximum hardness.

†After rough machining, anneal at 1450 degrees Fahr., air cool, finish the machining and then carburize.

Notes About the Process

The mixture of the carburizing compound is left to the judgment of the individual. Some add only enough new compound to replace the amount used during carburizing, while others may vary the ratio from the above to a mixture of 50 per cent old and 50 per cent new.

There are several methods used for packing the camshafts. For example, a single shaft may be packed in a tube or a number of shafts may be packed in a tube or a box of suitable size. The majority of the methods give good results if properly carried out.

When using the plain carbon steel (S. A. E. 1020), satisfactory results may be obtained without annealing or otherwise heat treating before machining, although by following the above practice, the steel will be in a better condition.

When using a salt bath as a heating medium for hardening, the shafts are sometimes preheated at approximately 600 degrees Fahr., transferred to the salt bath in which they are suspended vertically to prevent warping and maintained in the heating medium until they attain the proper hardening temperature. They are then quenched and tempered.

Recommended Practice for the Carburizing of Gears

General

This recommended practice covers the process to be followed

in the carburizing and heat treatment of gears. The process of carburizing will be here considered as the pack method.

Chemical Composition

There are steels of other analyses used for gears, than those listed below, but they require special heat treatments and, therefore, this recommended practice does not apply to them.

The steels generally used for gears have the following chemical composition:

Chemical Composition

Steels	C	Mn	P Max	S Max	Ni
C	0.10–0.20	0.30–0.60	0.045	0.05	.....
1.5% Ni*	0.10–0.20	0.30–0.60	0.040	0.045	1.25–1.75
3.5% Ni*	0.10–0.20	0.30–0.60	0.040	0.045	3.25–3.75
5% Ni*	0.17 max.	0.30–0.60	0.040	0.045	4.50–5.25
Ni-Cr[1]	0.10–0.20	0.30–0.60	0.040	0.045	1.00–1.50
Cr-V[2]	0.12–0.20	0.55–0.75	0.040	0.040	.....

*For most uniform and satisfactory results the carbon content for these steels should be within a five point range.

[1]The chromium content for this steel is 0.45 to 0.75 per cent.

[2]The chromium content for this steel is 0.70 to 1.00 per cent, and the vanadium content is 0.15 to 0.20 per cent.

Annealing After Forging and Before Machining

For annealing the 1.5 per cent nickel, 3.5 per cent nickel, nickel-chromium, and chromium-vanadium steels, place the steel in the furnace to expose maximum surface area. Heat slowly and uniformly to a temperature of 1600 to 1650 degrees Fahr., and cool at a rate to give the desired machinability.

For annealing the 5 per cent nickel steel, place the steel in the furnace so as to expose maximum surface area. Heat slowly and uniformly to 1600 degrees Fahr., and hold at this temperature for about one hour. Cool in furnace, allowing from 5 to 8 hours for the steel to become cold.

To obtain the best condition for machining and grain size, it is sometimes desirable to heat the 5 per cent nickel steel to 1600 degrees Fahr. and quench in water or oil. Then anneal to give a Brinell hardness number from 163 to 179.

Carbon Content of Case

The carburizing process should be so carried out that the carbon content of the outer portion of the case will be approximately 1.00 per cent.

Table I

Carburizing and Heat Treatments for Carburized Gears

Heat Treatment	Carburize at Deg. Fahr.	Quench	Reheat to Deg. Fahr.	Quench in	Reheat Deg. Fahr.	Quench in	Purpose of Heat Treatment (See Footnotes)
			CARBON STEEL				
1	1600–1650	From Box into Water	1425–1450	Water	.....	.....	A
2	1600–1650	Cool in Box	1625–1650	Water	1425–1450	Water	B
3	1600–1650	Cool in Box	1425–1450	Water	.....	.....	C
			NICKEL STEELS				
4	1600–1650	From Box into Oil*	1300–1350	Oil†	.....	.....	A
5	1600–1650	Cool in Box	1550–1600	Oil	1325–1375	Oil	B
6	1600–1650	Cool in Box	1325–1375	Oil	.....	.....	C
			NICKEL-CHROMIUM AND CHROMIUM-VANADIUM STEELS				
7	1600–1650	From Box into Oil*	1400–1425	Oil†	.....	.....	A
8	1600–1650	Cool in Box	1575–1600	Oil	1400–1425	Oil	B
9	1600–1650	Cool in Box	1425–1450	Oil	.....	.....	C

[1]All gears should be tempered at 300 to 350 degrees Fahr., except clash gears which are tempered at 350 to 400 degrees Fahr.

*The purpose of this quench is to hold the cementite in solution.

†The oil for this quench should be flowing rapidly.

Purposes of Heat Treatments

A. To be used when hardness and toughness are both governing factors.
B. To refine case and core.
C. To be used when distortion is governing factor.

Depth of Case

The depth of case on each side of the gear tooth should be about 15.00 per cent of the total thickness of the tooth, measured at the pitch line.

Copper Plating

Where it is desired to keep a portion of the work soft after heat treatment, to permit machining or to assist in controlling distortion, copper plating to prevent the penetration of carbon is recommended.

Bevel Gears

When quenching bevel gears the last operation should be done on a quenching machine with a properly designed die.

Heat Treatments

The carburizing and heat treatments for the steels considered in this recommended practice are given in Table I.

EXPERIMENTS WITH NICKEL, TANTALUM, COBALT AND MOLYBDENUM IN HIGH SPEED STEELS

By H. J. French and T. G. Digges

Abstract

This is a preliminary report concerned with the effects of chemical composition on lathe tool performance of high speed steels. With the exception of a chromium-tantalum steel all experimental steels are modifications of the high tungsten-low vanadium or low tungsten-high vanadium types now used industrially. In some cases, additions were made to the usual proportions of chromium, tungsten and vanadium, as in the steels containing nickel and cobalt, while in some steels such as those containing molybdenum or tantalum, the special elements were substituted for all or part of one of the customary constituents. Included in the experimental heats are two commercial steels which enable a direct comparison of "quality" between experimental melts and commercial steels of similar composition. Preliminary results suggest that the advantages gained by the additions of nickel and cobalt in high speed steel are associated with the heat treatment rather than the composition.

I. Introduction

TESTS described in this report form part of an investigation of the effects of chemical composition on lathe tool performance of high speed steels. Only roughing cuts will be considered and discussions will be further restricted to the preliminary tests on a few of the first steels made. This is, therefore, a progress report and cannot be expected to be complete.

Three factors are recognized as contributing in a major degree to the tool performance of that group of alloys called high speed steels, (1) heat treatment, (2) "quality" of the metal, (3) chemical composition. The general effects of heat treatment variations on commercial high speed steels have been so widely discussed that no comments need be added at this point. Of the

*Published by permission of the Director of the National Bureau of Standards of the U. S. Department of Commerce.

A paper presented before the Cleveland Convention of the Society, September, 1925. Of the authors, H. J. French is physicist (metallurgy), and T. G. Digges, associate physicist (metallurgy), with the Bureau of Standards, Washington, D. C.

two remaining factors most importance is usually attached to the "quality" of the steel, at least in manufacturers' statements. In the term "quality" are grouped all manufacturing variables, other than chemical composition, which tend to produce good or bad steels and these surely play an important part in the behavior of any steel, whether of high speed or other types. However, as already pointed out by the authors and others, the chemical composition is likewise of importance and cannot be entirely disregarded. That this is true and likewise recognized by producers is shown by the effective chemical standardization of commercial steels, despite the fact that today they are still marketed under trade names.

Admitting the importance of this factor, it is interesting to note that but two major improvements have been recorded since the publication in 1906[1] of Taylor's investigations. The first and most important is an increase in vanadium content; the second is the addition of cobalt.

It is now an accepted fact that current commercial high speed steels, with from 3 to 7 times the vanadium found in the best of Taylor's steels, are superior in many respects for roughing work to the low-vanadium or vanadium-free alloys. However, differences of opinion exist with respect to the use of a few per cent of cobalt.

In the investigation in which this forms a preliminary report three useful fields of study were kept in mind: (1) An improvement in tool performance even at increased cost (the improved performance should preferably be commensurate with the increase in cost): (2) A reduction in the total proportion of alloying elements in the steel (likewise a reduction in cost) while retaining present performance; (3) The effect of impurities ordinarily encountered on the performance of current commercial high speed steels. The special steels dealt with in this report are not all new but in such cases cover modifications of customary compositions concerning which more data are needed, and the results may, therefore, also be of interest at this time.

II. Steels Tested

The chemical compositions of the high speed steels tested are given in Table I. Included in the twelve heats listed are two commercial steels made by representative manufacturers; these

[1] F. W. Taylor: The Art of Cutting Metals. *Transactions*, A. S. M. E., 28.

Table I
Chemical Compositions of the High Speed Steels Tested[1]
(analysis on samples from ingots)

Heat	Steel Type	Chemical Composition — per cent											
	Ordinary Compositions	C	Cr	W	V	Mo	Co	Ni	Ta+ Cb	Mn	P	S	Si
I	High W-low V (commercial)	.63	3.97	18.88	.81	....	....	.15	....	.29	.012	.024	.25
E21	High W-low V (commercial)	.70	3.79	17.90	1.01	....	....	.15	....	.27	.038	.060	.44
L	Low-W-high V (commercial)	.71	3.60	12.75	1.99	....	....	....	....	.31	.029	.026	.24
E15	Low W-Co	.76	3.75	13.55	1.99	....	3.68	.22	....	.37	.048	.115	.63
	Steels with Nickel												
E22	High W-Ni	.61	3.66	17.40	1.02	....	....	3.71	....	.24	.043	.073	.55
E14	Low W-Ni	.69	3.64	13.75	1.92	....	....	3.70	....	.39	.057	.125	.59
E41	Low W-Ni (low carbon)	.51	3.85	12.72	1.95	....	....	3.54	....	.27	.019	.020	.39
	Steels with Molybdenum												
E29	W wholly replaced by Mo	.71	4.74	.....	.54	7.07	....	....	....	.33	.013	.019	.48
E31	W partly replaced by Mo	.53	3.40	11.95	1.04	3.41	....	....	....	.31	.017	.023	.27
	Steels with Tantalum												
E23	Cr-Ta Steel	.69	4.28	.....	.08	....	....	.13	3.45	.44	.023	.018	.55
E16	V replaced by Ta + Cb	.76	3.61	11.50	.06	....	....	.05	5.08	.35	.027	.020	.50
E42	W partly replaced by Ta + Cb	.69	4.23	8.17	1.58	....	....	....	6.05	.37	.008	.018	.44

[1]All analyses were made by Messrs. W. C. Fedde and C. P. Larrabee of the Chemistry Division, Bureau of Standards.

Table II
Detailed Record of the First Reduction in Forging Some of the High Speed Steel Ingots

Ingot	Charged Preheat Furnace	Withdrawn Preheat Furnace	Temp. Preheat Furnace at Withdrawal. °F.	Withdrawn Forging Furnace	Temp. Forging Began °F	Temp. Forging Ended °F	Time Forging Ended	Withdrawn Forging Furnace	Temp. Forging Began °F	Temp. Forging Ended °F	Time Forging Ended	Size Inches
E21	10 P. M. 4/7/25	9:40 A. M. 4/8/25	1610*	9:52	2085	1785	9:55	10:03	2070	1746	10:05	1⅝x1⅞
E15	"	10:10	1620	10:20	2075	1785	10:22	10:30	2110	1934	10:31	2⅛ sq. appr.
E14	"	10:35	"	10:45	2090	1798	10:47	10:58	2110	1874	11:00	2⅛ sq. appr.
E22	"	10:45	"	11:00	2120	1785	11:02	11:10	2110	1862	11:11	2 sq. appr.
E16	"	11:05	"	11:16	2170	1818	11:18	11:27	2170	1862	11:29	2 sq. appr.
E29	"	11:16	"	11:34	2110	1772	11:36	11:45	2140	1850	11:47	2⅛ sq. appr.
E23	"	11:48	"	11:57	2130	1824	11:59	12:06	2170	1868	12:08	2 sq. appr.

*Temperature up since 6:30 A. M.

enable direct comparison of "quality" between the experimental melts and commercial steels of similar compositions and so indicate the importance of changes resulting from variations in composition in relation to steels now generally available. With the exception of the chromium-tantalum steel (heat E23, Table I) all steels are modifications of the high tungsten-low vanadium or low tungsten-high vanadium types now used industrially. In some cases additions were made to the usual proportions of chromium, tungsten and vanadium, as in the steels containing nickel and cobalt, while in some steels such as those containing molybdenum or tantalum the special elements were substituted for all or part of one of the customary constituents.

III. Melting Practice Employed

All experimental heats were made in an electric furnace of the indirect arc type recently installed at the Bureau of Standards (Fig. 1). A similar furnace and its application to the production of special steels were described by Gillett and Mack,[2] but in the present unit the lining consisted of coarse dry ground electrically sintered magnesia bonded with water ground electrically sintered magnesia. The practice employed consisted in melting a charge of desired composition directly under the arc without an intervening slag either for protection or the removal of impurities; with the exception of ferrochromium, ferrovanadium and ferrotantalum and half the required ferromanganese and ferrosilicon, all raw materials were charged at one time and the furnace was well sealed during the melting stage. American ingot iron was used as a base, and chromium, vanadium and tantalum, when required, were added a few moments before tapping. Half of the ferro-alloys of manganese and silicon were added with a small amount of aluminum in the ladle.

The metal was generally tapped hot enough to permit holding in the ladle for a few moments before casting into 55-pound ingots having a top section about 3 inches x 3 inches and a length of 22 inches. A split iron mold was used in which the ratio of mold to ingot weight was about 1.9; in practically all cases hot-tops were employed and a top discard made of from 10 to 25 per cent.

[2] H. W. Gillett and E. L. Mack: Experimental Production of Alloy Steels, Bureau of Mines Bulletin 199 (1922).

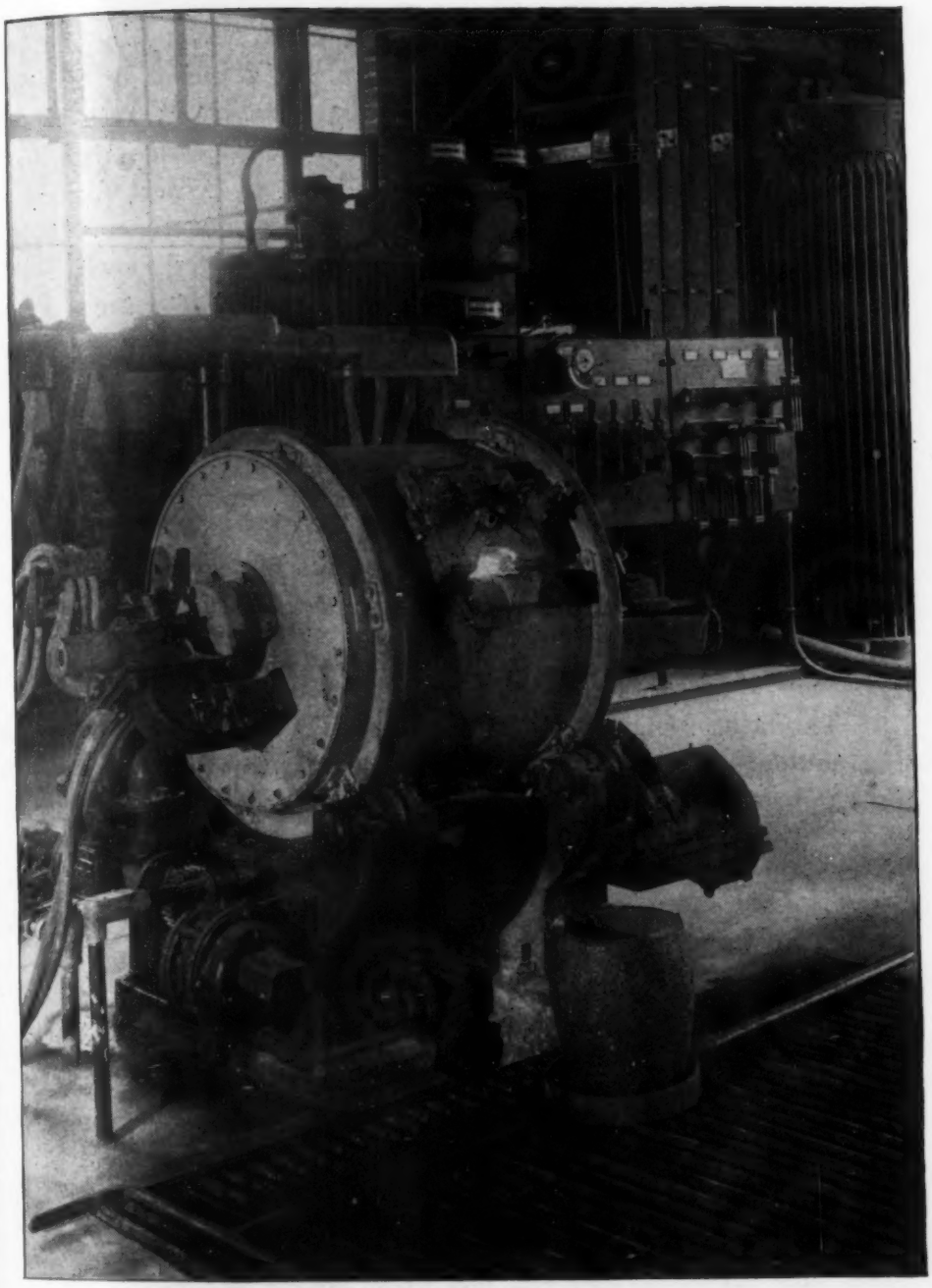

Fig. 1—Indirect Arc Furnace at the Bureau of Standards which was Used for Producing the High Speed Steels Tested. The Shell Shown is Lined for Brass Melting; It Differs only in this Respect from the Steel Melting Unit.

IV. Forging of the Ingots

Ingots were annealed by heating for from 1½ to 2 hours at 1700 degrees Fahr., followed by furnace cooling. Subsequently, all surfaces were ground or machined to remove defects. Forg-

ing was carried out in two steps at the U. S. Naval Gun Factory; the ingots were first reduced to bars about 2 inches by 2 inches, then reheated and reduced to the final size of ¾ inch by 1¼ inches. Forging was done with a 1700-pound steam drop hammer, and temperatures were controlled by an optical pyrometer. Two-stage heating was used for all forging operations. In general the metal was charged into a cold furnace and slowly heated to a definite temperature between 1450 and 1600 degrees Fahr., then introduced into the high-heat furnace, and removed as soon as uniformly heated to the desired forging temperature. The initial temperature of forging was kept between 2100 and 2200 degrees Fahr. and the finishing temperature between 1700 and 1800 degrees Fahr. A detailed record of the first reduction of some of the ingots is given in Table II and will show the care used in the preparation of bars from which the lathe tools were taken. Forged bars were annealed by heating for about 3 hours at either 1600 or 1650 degrees Fahr. and furnace cooling.

V. Preparation of the Tools and Methods of Test

The lathe tools had a cross section of ½ inch by ¼ inch, and the methods of heat treatment were identical with those used in previous investigations which have already been described in detail.[3] Tools were ground to front and side clearances of 6 degrees, side slope of 14 degrees, back slope of 8 degrees, and had a nose radius of ⅛ inch. The top surfaces of the tools were ground on metal coming from the outer section of the larger forged bars from which the tools were cut.

The cutting angle (tool to surface of test log) was 90 degrees, and the tool nose was set at dead center. Except when otherwise indicated the tools were run dry at 85 feet per minute, calculated at the bottom of cut, with a feed of 0.028 inch and a depth of cut of $\frac{3}{16}$ inch. The chemical and physical properties of the test logs used, which were all taken from one large forging are given in Table III.

VI. Experimental Results

1. *Comparison of Experimental and Commercial Steels of Similar Compositions*

As already pointed out tool life may be materially affected by variations in factors other than chemical composition, so that

[3] H. J. French, Jerome Strauss and T. G. Digges: Effect of Heat Treatment on Lathe Tool Performance and Some other Properties of High Speed Steels. Transactions, A. S. S. T. 4, p. 353 (1923).

it will be well to first consider the relation between the experimental and similar commercial steels. Variations in the "quality" factor are probably at a minimum in the various experimental heats as these were all made, with one exception, from the same raw materials, by the same operators in the same equipment

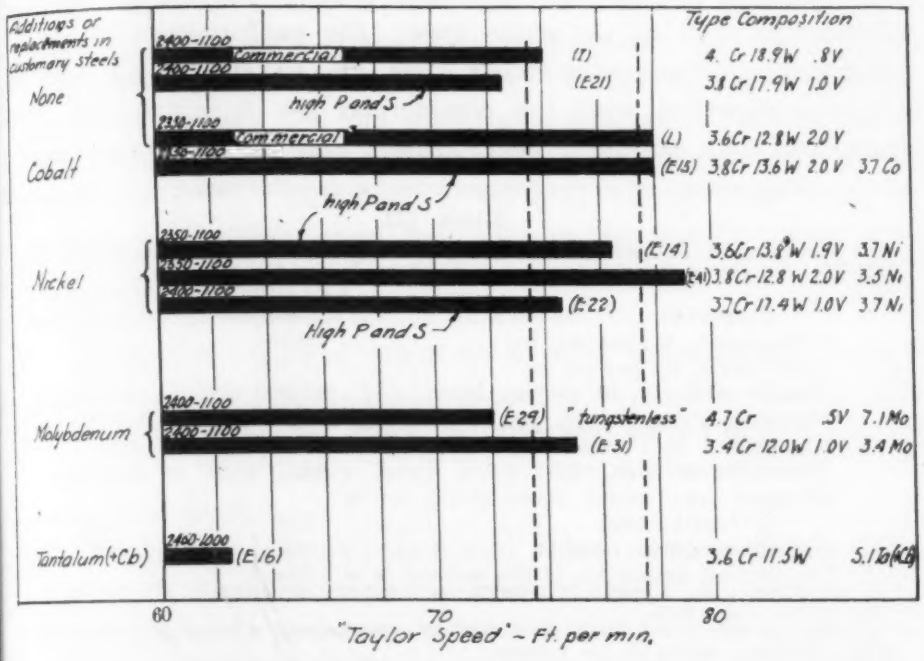

Fig. 2—Graphical Comparisons of the "Taylor Speed" of High Speed Steels of Various Types. The Figures Given at the Left Side of the Chart, Above Each Black Line, as for example "2400—1100," refer Respectively to the High Heat Temperatures Used in Hardening and Subsequent Tempering. All Temperatures are Given in Degrees Fahr. For Details of the Conditions of Test and Other Data refer to the Text of the Report.

and by as nearly the same methods of melting, forging and treatment as possible. The point of particular interest is how real, in relation to current commercial steel performance, are the changes to be described from variations in the chemical composition.

As is shown in Table I the majority of the experimental heats are higher in silicon than the commercial steels, and contain up to about 0.6 per cent. Likewise four contain high phosphorus and sulphur. These latter elements were inadvertently introduced in large quantities by the first lot of ferrovanadium employed (it will be noted that steels with 2 per cent vanadium have about twice the proportions of phosphorus and of sulphur as do the steels with 1 per cent); another lot of ferrovanadium

was used for the remaining heats and these have more nearly the customary amounts of phosphorus and sulphur.

It will be evident from examination of Table IV, that the tool performance is not appreciably affected by these variations in composition. For example, the experimental high tungsten-low vanadium steel (E 21) has only slightly shorter life than the commercial steel of the same type; the performance of the experimental low tungsten-cobalt steel (E 15) is for all practical purposes identical with the commercial low tungsten-high vanadium steel (L), similarly heat treated, and the two nickel-bearing

Table III

Mechanical Properties of the Test Logs Used for Lathe Tests[1]

Properties	Test values at a diameter of 9.5 inches	5 inches
Prop. limit, lb. per sq. in.	25,000	51,000
Yield point, lb. per sq. in.	53,700	52,700
Tensile strength, lb. per sq. in.	87,300	87,300
Breaking strength,[2] lb. per sq. in.	152,800	146,300
Elongation in 2 inches, %	29.5	29.0
Reduction of area, %	55.7	52.7
Relative area under stress-strain curve of tensile test	1.00	1.03
Brinell hardness number	169	169

[1]The chemical composition of this material is as follows: C, 0.31%; Mn. 0.56%; P. 0.040%; S. 0.027%; Si. 0.31%; Ni, 3.27%; Cu. 0.26%.

Prior to test it was annealed by heating approximately 4 hours at 1460 degrees Fahr. and then cooling in the furnace.

[2]This is the unit load at moment of fracture and is equal to the total load divided by the reduced area of the fractured section.

heats of the same type (E 14 and E 41) have respectively slightly shorter and a little longer life than this commercial product.

Such variations as exist are not large, viewed either from the life of the tools or the "Taylor speed"[4] and it may, therefore, be said that the experimental heats of similar compositions are generally comparable, insofar as roughing lathe tool performance is concerned, to good commercial steels.

2. Effect of Nickel and of Cobalt in High Speed Steels

No unusual characteristics were observed in the melting, casting or forging of the high speed steels containing nickel or cobalt. As far as could be determined these behaved exactly like similar

[4]The "Taylor speed" is the speed which causes the tools to fail in exactly 20 minutes. If the life of the tools is known under fixed cutting conditions the Taylor speed may be calculated from the equation:

$$\text{Taylor speed} = \frac{\text{a constant}}{(\text{tool life})^{1/7}}$$

Data from which this equation was developed will be presented in a subsequent report. All values here used have been so calculated.

steels free from or with less than a few tenths of one per cent of these elements.

It will be noted from comparisons given in Table IV that provided the same heat treatments are used no appreciable change in tool life (or Taylor speed) is produced by the addition of 3½-3¾ per cent nickel to either the low tungsten or high tungsten types of high speed steel. The performance of the first seven steels shown at the top of Fig. 2 is characteristic of the tungsten-vanadium content and not materially affected by either the presence or absence of nickel or cobalt (refer to the vertical dotted lines in Fig. 2). Certainly nickel does not in these steels exert a deleterious effect upon tool life or the speeds which can be used in rough turning but it is responsible for other undesirable effects which will shortly be discussed.

Hoffman[5] reported tests of a high tungsten-low vanadium steel containing about 1¾ per cent nickel. He stated, "Steels of this type did good work in ordinary shop practice but when subjected to fast heavy work they were no better than standard high speed steel."

While the authors' tests and those mentioned by Hoffman show no marked change in the performance of finished tools there is evidence that the introduction of appreciable proportions of nickel adversely affects the machining qualities of the metal. It was found impossible to machine heats E 22 and E 14 (which contain no more than the customary proportions of carbon), either in the cast or forged conditions even after prolonged annealing. For this reason the lower carbon heat, E 41, was made. This showed somewhat longer tool life than the steel with higher carbon (it also has lower phosphorus and sulphur) and could be machined without difficulty after annealing; however, it was not "soft." Thus one of the undesirable effects of nickel additions is to make difficult or impossible the machining of such high speed steels of otherwise ordinary compositions, but this may be counteracted to some extent by reducing the carbon content to about 0.5 per cent.

The hardness values of heat treated high speed steels containing 3¾ per cent nickel and the changes in hardness upon tempering appear to be about the same as those found in similar

[5]Discussion of report by J. A. Mathews: Modern High Speed Steel. *Proceedings*, A. S. T. M., *19*, p. 178 (1919).

Table IV
Lathe Tool Performance of Various High Speed Steels Heat Treated in Various Ways

Tests on Log No.	Tool Steel heat No.	Type of high speed steel	Heat Treatment: Pre heat 20 min at °F	High Tempered heat, 30-45 min 1.5 min at °F		Tool Life in Minutes: 1st grind 1	1st grind 2	1st grind 3	1st grind 4	1st grind 5	2nd grind 1	2nd grind 2	2nd grind 3	2nd grind 4	2nd grind 5	Av. both grinds	Av. energy consumed by tools. watts	Remarks Taylor Speed
17	1	18% W (commercial)	1600	2400 (a)	1100	6.0	4.9	6.0	8.7	...	8.2	4.2	9.5	11.7	...	7.4	3720	74
17	E21	18% W	1600	2400	1100	5.0	5.7	7.2	...	...	7.5	4.3	10.0	4.8	...	6.8	3630	72.5
17	L	13% W (commercial)	1600	2370	1100	9.9	14.0	9.1	15.3	...	...	...	...	...	...	(12.1)	(3820)	79
18	L		1600	2350	1100	16.8	10.5	14.3	10.9	...	11.3	8.4	7.9	8.0	...	11.0	3740	78
18	E15	Low W—cobalt	1600	2350	1100	9.4	12.0	8.1	16.3	...	12.0	10.2	13.3	7.8	...	11.1	3480	78
17	E15		1600	2400	1100	11.1	13.6	16.5	13.1	...	17.4	...	15.9	...	...	14.6	3910	81
18	E22	High W—nickel	1600	2200	1100	1.6	1.7	1.6	...	...	1.3	1.5	1.7	...	...	1.6	....	60
18	E22		1600	2300	1100	3.7	5.9	4.5	...	...	3.1	3.5	3.4	...	...	4.0	3520	69
18	E22		1600	2400	1100	7.5	8.0	7.2	9.0	...	5.7	...	7.0	...	...	7.4	3730	74.5
18	E22		1600	2500	1100	11.0	8.3	9.3	...	...	5.9	9.5	9.8	...	...	9.0	4190	76.5
18	E14	Low W—nickel	1600	2300	1100	5.9	6.9	9.4	...	...	6.3	6.5	8.3	...	...	7.2	3540	74
18	E14		1600	2400	1100	9.2	14.3	11.9	...	...	10.3	12.8	9.6	...	...	11.4	3610	78.5
18	E14		1600	2475	1100	13.7	13.2	14.0	...	...	10.2	...	9.9	...	...	12.2	3680	79.5
18	E41	Low W—nickel (low carbon)	1600	2400	1100	13.5	11.8	12.4	...	...	14.3	14.3	8.8	...	...	12.5	3720	79
17	E23	Cr-Ta	1600	2400	650	0	0.2	0.2	0.1	...	0.2	0.1	...	...	...	0.1	....	...
17	E16	Cr-W-Ta	1600	2450	1000	1.3	1.8	2.4	2.9	3.3	1.4	1.3	3.0	2.0	...	2.2	3580	62.5
18	E42	Cr-W-V-Ta	Would not harden or cut															
18	E29	"Moly." high speed	1600	2200	1100	3.5	3.5	4.0	4.9	...	4.7	6.4	3.4	2.9	...	4.2	3610	69
			1600	2300	1100	4.6	2.9	4.8	5.9	...	5.4	6.3	3.9	5.0	...	4.9	3650	70.5
			1600	2400	1100	4.5	9.6	6.6	4.8	...	4.4	7.5	5.7	3.8	...	5.9	3590	72
			1600	2475	1100	5.0	5.4	4.1	B	...	5.7	5.5	5.6	5.8	...	5.3	3510	71.5
18	E31	Cr-W-Mo-V	1600	2400	1100	9.0	8.9	5.4	...	...	6.6	10.1	7.6	...	...	7.9	3610	74

(a) Subsequently quenched in oil.
B = tool broke.
Note: Logs 17 and 18 were taken from one forging.

steels without nickel or with cobalt when the Brinell, Shore and Rockwell methods are used. Typical hardness test results which can be compared with data on the customary compositions, already published, are given in Fig. 3.

As is well known, small proportions of nickel, of the order of a few tenths of one per cent, are frequently found in commercial high speed steels. In view of the described results it is not to be expected that as an impurity in the specified quantities

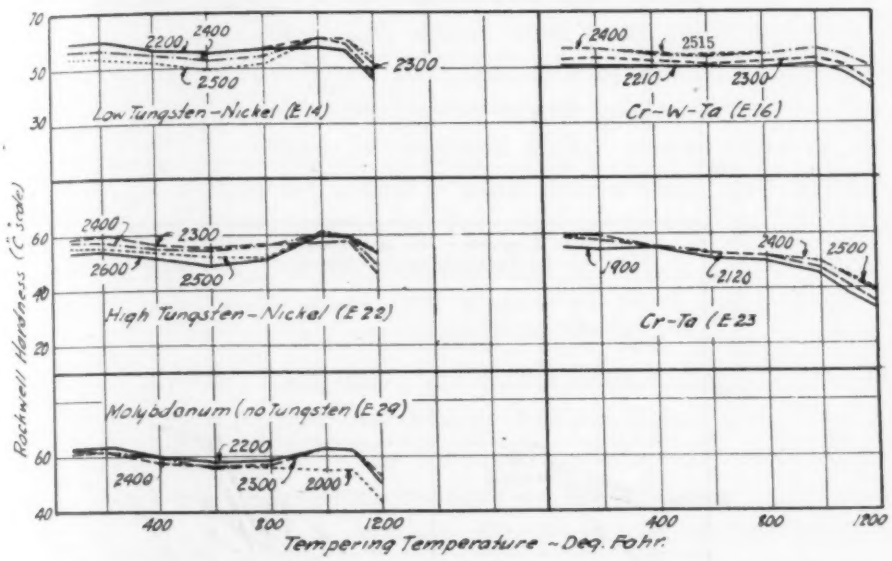

Fig. 3—Rockwell Hardness Values ("C" Scale) of Various High Speed Steels Heat Treated in Various Ways. The Numbers Placed on the Curves Represent the High Heat Temperatures (in Degrees Fahr.) Used in Hardening. For the Compositions of the Various Steels refer to Table I.

nickel will noticeably affect the handling of the metal or contribute to any extent to changes in performance of tools for roughing work. This comment is made, as there has recently been formed by the American Society for Testing Materials a committee to study the effects of nickel, copper, tin and other elements which may be encountered as impurities in commercial production of high speed steels.

Mention has already been made of differences in opinion on the value of cobalt additions to the customary types of high speed steels. In commercial material from about 3 to 5 per cent is found. The authors' previous investigations have led to the conclusion that distinct benefits are derived but these have been entirely associated with modifications in heat treatment. As low tungsten-high vanadium steels with cobalt are not regularly man-

ufactured most of previous work has been with the high-tungsten cobalt type. It is therefore, of interest to point out again at this time that the performance of the low tungsten-cobalt heat (E 15)

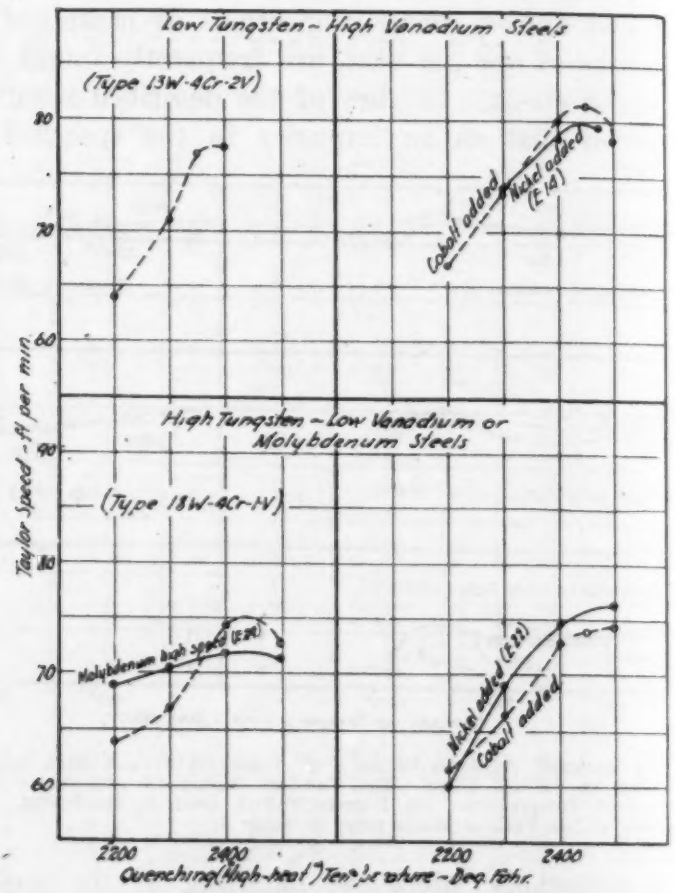

Fig. 4—Effect of High Heat Temperature Used in Hardening on the "Taylor Speeds" of Various High Speed Steels. Dotted Lines Between Hollow Circles Represent Steels Tested in Another Investigation (Refer to Footnote (3) of the Test). These Steels were Tested on Different "logs," Having Somewhat Higher Hardness, than those Used for the Special Steels in this Investigation which are Represented by Solid Lines Between Solid Circles. Direct Performance Comparisons Should therefore not be Attempted Between Steels of the Two Groups. Subsequent to Hardening all Steels Were Tempered for about 30 Minutes at 1100 Degrees Fahr.

is no better than the same steel without cobalt when heat treated in the same way.

To obtain advantages from the customary cobalt additions higher temperatures must be used in hardening, as is shown by the high-heat temperature-"Taylor speed" curves given by dotted lines between hollow circles in Fig. 4. These steels were tested

in a previous investigation[6] on various nickel steel test logs having tensile strengths between about 100,000 and 125,000 pounds per square inch. Numerical values for the Taylor speed must not be directly compared, one steel to the other, or with the special alloys made up for this investigation, which were tested on softer logs. However, the curves do show the effects on performance of variations in high-heat temperature and it is for this reason that they are reproduced.

As shown in Fig. 4, the addition of about 3.7 per cent of nickel to the customary high speed steel compositions produces effects similar to those from like amounts of cobalt. The peaks of the high-heat temperature-Taylor speed curves occur at about equal temperatures some 50 degrees Fahr. above those in like steels without nickel or cobalt. Thus to develop best performance, higher temperatures must be used in hardening the steels with nickel just as for steels containing cobalt.

Cobalt high speed steels are known to react more slowly in heat treatment than the customary steels and have, therefore, been referred to as "sluggish." To this feature may be ascribed the necessity for higher hardening temperatures and, likewise, the better performance. The various constituents, once brought into solution by higher temperatures or longer times at temperature or both, are not so readily reprecipitated under otherwise comparable conditions. Both nickel and cobalt appear to exert like effects in this respect.

3. High Speed Steels Containing Molybdenum

Since Taylor's investigations considerable attention has been given to the use of molybdenum in high speed steels usually as a complete replacement of tungsten; additions or partial replacements have, however, also been considered, and are now found in some commercial products. It is not practicable to include in this report a detailed review of the numerous publications relating to this subject; instead a brief summary of important features will be given.

Molybdenum when present in sufficient amounts imparts to steel the properties of "red hardness" but its use in place of tungsten (in the customary types of steel) has not yet passed much beyond the experimental stage. Its effectiveness in permit-

[6] Refer to footnote 3.

ting tools to operate under the most severe conditions is, perhaps, well shown by the fact that similar results have been obtained with about 7 per cent molybdenum as with 2 or 2½ times this amount of tungsten. However, such steels have certain marked disadvantages; the molybdenum has a tendency to "sweat out" during the progress of manufacture subsequent to melting, and difficulties have been encountered in reproducing good tool performance from successive heats of steel. To overcome this the addition of cobalt has been suggested as a "stabilizer" but it is not clear by just what mechanism such a result is obtained, if at all.

In the two molybdenum steels considered in this report one has a complete replacement of tungsten in the ratio of one part molybdenum to 2½ parts of tungsten; the second has a partial replacement of tungsten (6 per cent) with about half as much molybdenum. Both are modifications of the commercial high tungsten-low vanadium type of steel. Unfortunately, however, the tungstenless heat is low in vanadium so that a somewhat poorer performance would be expected than if the customary one per cent were present. While tools made from this steel are inferior to the customary commercial types when quenched from temperatures around 2400 degrees Fahr. and subsequently tempered at 1100 degrees Fahr., their performance is much less dependent upon the high-heat temperature used in hardening than is the case with the tungsten steels, and so with the low hardening temperatures show somewhat longer life than the latter. This is well shown in Fig. 4.

Tools made from heat E 31 in which about 3.4 per cent molybdenum has replaced about 6 per cent tungsten show slightly longer life than tools of the "standard" 18 per cent tungsten type, but this appears to be offset by difficulties encountered in forging.

The same practice and careful control were meaintained in forging the molybdenum steels as with the other alloys, but in both heats the ingots cracked badly and only a small proportion was secured in final bar form. The tungsten-molybdenum steel (E 31) was, perhaps, much the worst in this respect as the ingot split under the first few light blows of the hammer. Possibly a modification in forging practice combined with changes in melting would have been productive of better results, but it is clear

that these molybdenum steels are more sensitive to working conditions than the ordinary types of high speed steels. So-called "sweating out" of the molybdenum visible by the thick bluish smoke arising from the steel, was only observed during forging.

In brief, these tests confirm the present more or less general viewpoint that molybdenum as a replacement of all or a large part of the tungsten in the current commercial types of high speed steels is not desirable.

Since carrying out these tests Hohage and Grützner[7] published data for a variety of high speed steels of special composition and it is interesting to note that their results also show no advantage in replacing part of the tungsten by molybdenum. Two of their steels may be referred to for comparison, as follows:

Steel	C	Cr	W	V	Mo	Relative
	%	%	%	%	%	performance
23	0.79	3.18	12.40	0.52	3.98	1.00
8	0.63	3.14	18.70	0.49	...	1.02

The Rockwell hardness values of the molybdenum steel (tungstenless), E 29, when hardened and tempered in various ways are given in Fig. 3. Rehardening upon tempering and the numerical values obtained are quite similar to those for the customary types.

4. Steels with Tantalum (and Columbium)

The use of tantalum in tool steels is a subject which has so far received little attention. Sometime ago verbal reports were received by the authors concerning investigations carried out in England in which it was said that fairly satisfactory performance was obtained; however, no details were forthcoming. G. L. Kelley[8] mentioned attempts to use tantalum and stated, "From its position in the periodic table, this (tantalum) might be expected to show effects similar to those of vanadium. Our experiments so far, however, have not shown any advantage to attend its use." More recently experiments have been in progress at the plant of an American manufacturer without any better results.

As practically no experimental data were available from which to determine the best lines of investigation, three heats were

[7] R. Hohage and A. Grützner: Schneidversuche mit Schnellarbeitsstahlen, *Stahl und Eisen*, July 9, 1925, p. 1126.

[8] Refer to footnote 5, p. 158.

made, in one of which (E 16) 2 per cent vanadium was replaced by about 5 per cent of tantalum (plus columbium); in the other two these elements replaced tungsten as shown in Table I.

Ferrotantalum of the following composition was used:

Carbon 0.21 %
Manganese 2.54 %
Silicon 3.38 %
Phosphorus and Sulphur—each low
Tantalum 72.2 %
Columbium 8.9 %
Tin less than 0.1 %

This was in granular form and was added in a sheet-steel container to the molten metal a few moments before tapping. Care was taken to ram this well below the surface of the bath as an aid in minimizing losses due to oxidation and to help introduction into the steel. Due to inexperience or unsatisfactory control the losses from the calculated proportions of tantalum and columbium were quite large in the first two heats. The recovery was only about 80 per cent but increased to 97 per cent in the third heat made.

As will be noted from the reported compcsition of the ferrotantalum used, there is present approximately one part of columbium for every eight parts of tantalum. While the steels will subsequently be referred to as tantalum steels it is to be understood that they also contain columbium. This element, if recovered in the same proportion as tantalum, is present in the steel in an amount equal to about $^1/_9$ of the total percentages given in Table I.

Tools first made from these steels were heat treated in an ordinary manner and under such conditions best performance was shown by E 16 in which the tantalum replaced the vanadium. However, even this steel is much inferior to the current commercial types for roughing tools, as is clearly shown in Fig. 2. Heats E 23 and E 42, in which tantalum has replaced respectively all and part of the tungsten, were worthless. Steel E 42, a chromium-tungsten-vanadium-tantalum steel, was the worst and would not cut at all; the whole front and side of the nose was rubbed off by the first thin chips as the tools were fed in by hand preparatory to taking a full cut (Fig. 5).

Upon investigation it was found that no appreciable hardening had resulted from preheating for 20 minutes at 1600 de-

grees Fahr. followed by introduction into a high temperature furnace at 2400 degrees Fahr. for 1½ minutes and quenching in oil. The tools had a Rockwell hardness ("C" scale) in the neighborhood of 28 and an equally low Brinell hardness number.

With ½ inch by ¼ inch tools and the equipment and procedure employed, the specified time at high heat is ample for the customary types of high speed steel, but it was recognized that

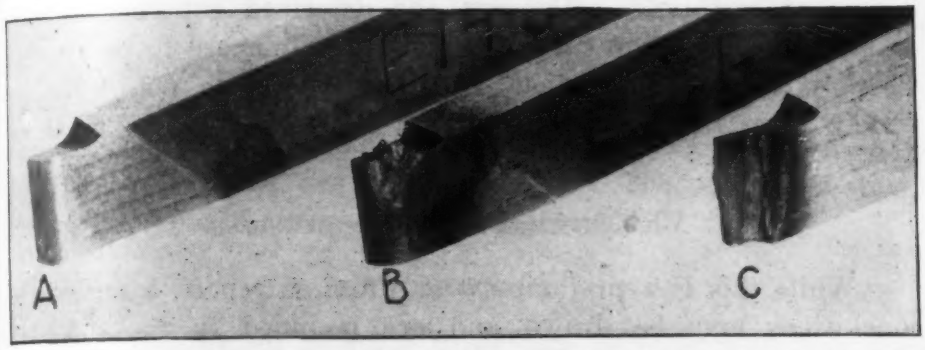

Fig. 5—Comparison of the Failure of Ordinary High Speed Steel Tools with Those from Heat E 42 which could not be Hardened. A—a New Tool; B—High Speed Steel Tool of Ordinary Composition after Failure; C—Tool from Heat E 42 after Failure.

this might not be so for the tantalum steels. Accordingly a set of quenching experiments was made, in which steel E 42 was subjected to different high heats between 2300 and 2600 degrees Fahr. for various periods between 1½ and 15 minutes both with and without preheating at 1600 degrees Fahr. At the highest temperatures where the steel had partially melted at the corners Rockwell hardness ("C" scale) as high as 50 was obtained, but at all other portions of the specimens no appreciable hardening resulted.

Tools so treated had a very coarse fracture, were extremely brittle and refused to cut. They either immediately broke in the body or the nose was rubbed off as previously described.

An increase in time at high temperature was also tried for the chromium-tungsten-tantalum steel (E 16). The tool life was slightly increased, from an average of 2.2 to about 3.3 minutes, but the steel was exceedingly brittle and in practically all cases broke in the body at the moment of failure of the nose.

Rehardening upon tempering was shown in the chromium-tungsten-tantalum steel (E 16), but not in the chromium-tantalum steel (E 23), which would not cut (Refer to Fig. 3). The latter decreased steadily in hardness as the tempering temper-

ature was increased; both showed somewhat lower values than the customary high speed steels. It should be noted that the maximum rehardening upon tempering in steel E 16 occurred at about 1000 degrees Fahr., roughly 100 degrees Fahr. lower than in ordinary high speed steels similarly hardened.

Further work is in progress with this and other special steels containing tantalum and, therefore, no conclusions will be drawn at this time. However, the described experiments seem to indicate that large proportions of tantalum are to be avoided. Possibly smaller proportions in steels which do not differ too widely from the current types will be productive of better results.

VII. Summary and Conclusions

While this is a preliminary or progress report, a number of conclusions may be drawn and are included in the summary below.

1. Roughing lathe tool performance of ordinary low tungsten-high vanadium and high tungsten-low vanadium high speed steels was not materially affected by the addition of 3.7 per cent of nickel, a like amount of cobalt or the replacement of part of the tungsten by molybdenum, but under the same heat treatments was characteristic of the tungsten-vanadium content.

2. To develop best tool performance higher hardening temperatures were required for the steels containing nickel than those without appreciable proportions of this element. In this respect nickel and cobalt are alike and the peak of the high-heat temperature-"Taylor speed" curves was found at approximately equal temperatures, some 50 degrees Fahr. higher than in the customary compositions. Nickel, however, adversely affected to a greater degree than cobalt, the "machinability" of the high speed steel. Two of the steels with nickel were non-machinable, but this undesirable feature was overcome, without adversely affecting tool performance, by reducing the customary 0.6 to 0.7 per cent carbon to 0.5 per cent. No unusual characteristics were developed in the forging of these steels.

3. Confirmation was obtained that molybdenum is not promising as a replacement of a large part or all of the tungsten in high speed steels. In one steel in which 3.4 per cent molybdenum replaced 6 per cent tungsten, slightly better tool performance

was obtained than with the customary high tungsten-low vanadium steel, but this appeared to be offset by difficulties encountered in forging. A steel in which 18 per cent tungsten was replaced by about 7 per cent molybdenum was affected to a much smaller degree by the high-heat temperatures used in hardening than are the customary commercial high speed steels. "Sweating out" of the molybdenum was only observed during forging.

4. Of three steels in which tantalum and columbium were substituted for other elements only one, containing about 3.5 per cent chromium, 11.5 per cent tungsten and 5 per cent tantalum in place of 2 per cent vanadium, showed "red hardness," i. e., cutting ability of the nature of ordinary high speed steels and its performance was relatively poor. The other two would not cut and one of these could not be hardened.

Acknowledgments

Acknowledgment is made to Jerome Strauss, materials engineer, U. S. Naval Gun Factory, for the forging of the special high speed steels, for supplying a quantity of ferrotantalum and the heat treated logs on which the tools were tested; to Messrs. W. V. Magruder, laboratory mechanic, and T. E. Hamill, laboratory assistant, Bureau of Standards, for carrying out many of the heat treatments, the majority of lathe tool and hardness tests. Acknowledgment is also made to H. W. Gillett, chief, Division of Metallurgy, and L. Jordan, chemist, Bureau of Standards for development of the special magnesite lining installed in the electric furnace.

Discussion

J. P. Gill—About four or five years ago the company with which the speaker is connected worked almost a year and a half on tantalum high speed steels. This company probably made up as many as one hundred different composition high speed steels containing tantalum, tungsten, chromium, vanadium and cobalt. Some of the heats made were as large as 7000 pounds. Lathe tests were run, many physical tests were made and it was found that several of the steels compared favorably with some of the regular high speed steels in commercial use today, but these steels were no better than the same steels without tantalum. We did not find any steels that were better than the regular high speed steels. Many things were learned in regard to the use of tantalum. The manner of introducing the tantalum into the steel and the form of the tantalum in the alloy apparently affected the results. The tantalum steels were found to be very dirty and full of oxides even when melted under the

best of conditions. Even in view of this fact, however, the tantalum steels seemed to be tougher than the standard types of high speed steel.

DR. J. A. MATHEWS: I would like to ask Mr. French whether in taking of samples for the molybdenum determination were they taken from hardened tools.

H. J. FRENCH: We took the forged and annealed bar and carefully pickled it in an ammoniacal citrate solution to loosen the adhering scale immediately below which our first cut was taken. There was no appreciable solution of the steel as far as we know, and it was necessary to actually chip loose the scale which was loosened by the pickling solution mentioned. This was not done on the ground tool, but on the forged bar which had been annealed.

DR. J. A. MATHEWS: If you do not find a loss by analysis, what is that yellow smoke that arises when molybdenum high speed steels are forged?

H. J. FRENCH: Perhaps you can tell us, Doctor.

DR. J. A. MATHEWS: I have always assumed that it was molybdenum trioxide. In hardening straight molybdenum high speed steels, I have noticed there is usually found a bark with a bright crystalline fracture something like cast antimony, but I have never analyzed it to see what it was, although I have assumed that it was due to loss of molybdenum. Were analyses made of the scale from molybdenum?

H. J. FRENCH: No, we did not analyze the scale. To do that would first require considerable material, and to get the molybdenum percentage we would also have to make an oxygen determination and attempt to predict what form of oxide we had on the surface, and that is not an easy matter like making a plain molybdenum determination.

CHAIRMAN SCHWARTZ: I have one question. There is a written request to please discuss nickel in high speed steels. "Do you find 3.75 per cent nickel not to be harmful, while nickel is ordinarily held to be harmful?" Do you wish to take that up at this time?

H. J. FRENCH: Yes. As shown in the report, the addition of 3.75 per cent nickel did not have a noticeably harmful effect on high speed steel tool life in roughing cuts, but it has a tendency, which is more marked than a similar tendency noticed for cobalt, to make the high speed steel itself non-machinable. We noticed no unusual characteristics in the working or the treatment of the nickel steels, but with normal carbon and normal amounts of other elements such as chromium, tungsten and vanadium, they are much harder than like steels without nickel. It was absolutely impossible to machine one of the nickel-bearing steels even after prolonged annealing, and it was for that reason that we made another heat with lower carbon. With the carbon reduced from 0.70 to 0.50 per cent, we found a marked improvement in the machinability; this steel was not so soft as the same steel without the nickel, but it was sufficiently soft and machinable so that ordinary cutting operations could be carried out with comparative ease.

We must remember that we are dealing with an alloy containing 18 per cent tungsten, about 4 per cent chromium and 1 per cent vanadium or some 23 to 25 per cent of alloying elements (other than iron and carbon) and

that the addition of small amounts of other elements is not in many cases to be expected to show such marked changes on physical properties as similar additions would show in the case of plain carbon steels. Manufacturers have for years emphasized the fact that quality, or those factors other than chemical composition, were as much, if not more important than the chemistry, and our results for nickel and other additions appear to check, at least in part, that viewpoint. However, some changes in chemical composition are of very great importance as, for example, the tungsten-vanadium relations; these control to a large degree, for steel of a given quality, the tool life. In a recent German work, which has just been published, it has been shown, that in the 13 per cent tungsten type of high speed steel, about 2 per cent vanadium—these are rough figures—gives the best tool life. The curve of tool life versus the vanadium content increases up to about 2 per cent, and thereafter it does not increase so rapidly, or may decrease,—I do not remember the actual figures. With the 18 per cent tungsten steel type, about 1.10 per cent was found to be the best. You may remember that Mr. d'Arcambal mentioned the change recently inaugurated by some of the manufacturers who have raised their vanadium content in the standard 18 per cent tungsten steels from about 0.75 per cent to 1.00 to 1.20 per cent. Those two independent sources of information checked up very nicely. However, nickel, when added to high speed steels, is on a different basis than for ordinary carbon steel or steel with lower proportions of alloying elements.

MEMBER: In adding 3 per cent of nickel to standard high speed steels, on annealing, we could not get the Brinell below 600. We could file it, but could not drill or machine it. We hardened it at temperatures up to 2400 degrees Fahr. and could never get it file hard. The Rockwell was around 50, whereas high speed steel is around 65. It was very, very brittle in the annealed condition, that is, to the impact test. The carbon was 0.65 to 0.70 per cent with the tungsten around 18 per cent, chromium about 4 per cent and vanadium 1 per cent. We were unable to anneal it, and I might say the shrinkage was very great. On high speed steel of standard analysis the density after hardening is less than in a similar steel containing from 1 to 3 per cent nickel.

A. H. KINGSBURY: Over 0.50 per cent nickel in milling cutters, forming tools, etc., is detrimental. I have had several experiences with that.

E. C. BAIN: I was glad to hear what Mr. French had to say about his analysis for molybdenum. The amount of oxide smoke which is given off from molybdenum at higher temperatures is highly misleading. Its volume would indicate in the case of swaging pure molybdenum metal that one was in imminent danger of losing the entire bar, but the actual loss is negligible. In the first place, molybdenum metal is not very volatile itself in the elemental state. The oxide is quite volatile. Even in vacuum at 3,000 degrees Fahrenheit molybdenum is volatilized very slowly. In the case of the steel, we should expect, inasmuch as the molybdenum is alloyed, that it would probably have a still lower vapor pressure and volatilize still more slowly.

That we should find that the amount of molybdenum in succeeding layers was essentially identical is to be expected for another reason, that molybdenum,

tungsten and chromium are alike in one respect, in fact, it may be that high speed steel is due entirely to this effect, that is, that they migrate very slowly, they have a very, very slow rate of diffusion, are sluggish as to diffusion of an iron material. Now, if the molybdenum can migrate only so very slowly in steel, then we shouldn't expect that we would establish a very long gradient in composition between the outside from which it was removed and the inside. As a matter of fact, all this volume of smoke comes from that part of the molybdenum which has already oxidized and is in the scale on the surface of the metal.

THERMAL DISTURBANCES AND RECRYSTALLIZATION IN COLD-WORKED STEELS

By V. N. Krivobok

Abstract

If metals, from 0.50 per cent carbon steel down to Armco iron are worked at room temperature and subjected to thermal analysis, they all show an evolution of heat, below the critical range, this evolution creating on the critical curve a point similar in every respect to standard critical points, but opposite in sign. It is arbitrarily designated the "Ax" point.

The position of the point is not always constant and fixed.

The Ax point is not of the reversible type: it disappears entirely after the first heating of the cold-worked sample. Hence its appearance must be closely connected with the specific properties imparted to a metal by cold working.

It seems quite reasonable to assume the Ax point indicates both recrystallization and a relief in internal strains.

The conclusions arrived at are based on the actual observations during the thermal analysis. Most of the curves that resulted from such an analysis are reproduced in the paper, as also are the results of microscopic examination.

THE general conception of recrystallization as applied to cast or heat treated steels is that the steel is heated above the critical range, well within the area designated on the temperature scale as the "granulation" zone.

In case of cold-worked metals, heating below the range is known to be sufficient to cause certain changes in the structure. Since these structural changes occur only in the cold-deformed metals, they must be closely connected with the characteristic properties of such metals. The most characteristic property, which can be conveniently called "the metastable equilibrium," is imparted to metals by cold-working.

Any change in the conditions of such equilibrium, brought

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about by artificial means, must result in the liberation of a certain amount of internal energy, temporarily stored in the cold-worked metals. It was thought that the freeing or liberation of such energy could be detected by some method of analysis.

It occurred to the writer that a piece of ordinary hypoeutectoid cast steel with a well developed structure, characteristic of such steel, would furnish a suitable sample for the experiment planned. An ordinary commercial steel with 0.50 per cent carbon was obtained and a piece of it, approximately ½x½x1 inch, cut off. This piece was hammered under a steam hammer until its cross section had been made $\frac{5}{16}$x$\frac{5}{16}$ inch. Care was taken that the blows of the hammer should be quite gentle; if this particular precaution were duly observed no cracking or other damage was noticed. From this "cold-worked" piece an ordinary sample, such as is used for the determination of critical points in steel, was turned.

For the thermal analysis was used a Leeds and Northrup transformation point apparatus, which employs two thermocouples and a neutral body sample holder. The sensitivity was made as large as possible without running off the chart when recording the standard critical points of the samples studied. An attempt was made (without resorting to special conditions) to maintain uniform heating and cooling of the samples. Heating from 500 to 1500 degrees Fahr. required ninety minutes and cooling two hours.

In Fig. 1 are reproduced the critical curves of a sample of the "as cast" steel already mentioned, having a carbon content of 0.50 per cent and cold-worked as described. The heating curve proceeds normally until a temperature of about 1200 degrees Fahr. is reached. At this point a rather sudden thermal disturbance takes place. This disturbance consists of a quite noticeable *evolution* of heat: this evolution is registered on the curve as a well developed critical point, but, naturally, opposite in sign to the points ordinarily observed. On cooling no similar disturbance takes place, which indicates that the newly observed thermal point is not the manifestation of a reversible allotropic transformation. In order to substantiate this observation a second sample of the same steel was similarly treated and a thermal curve was taken. The same point was again observed, although its position on the temperature scale was somewhat elevated. From the curve (Fig.

2) it can be estimated as taking place near 1270 degrees Fahr. A cooling curve was run on the same sample and again no evidence of the new point on cooling was found. The sample was allowed to remain in the furnace over night without disturbing

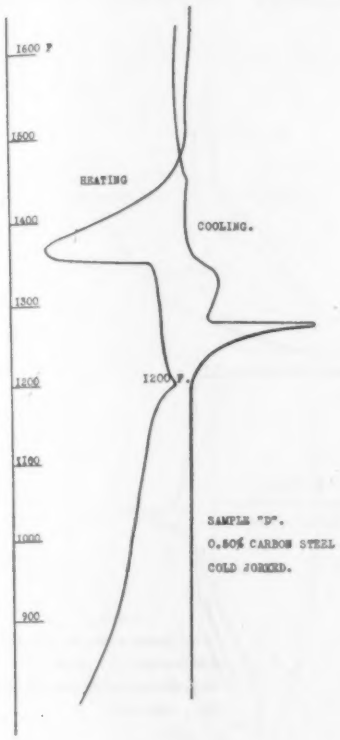

Fig. 1

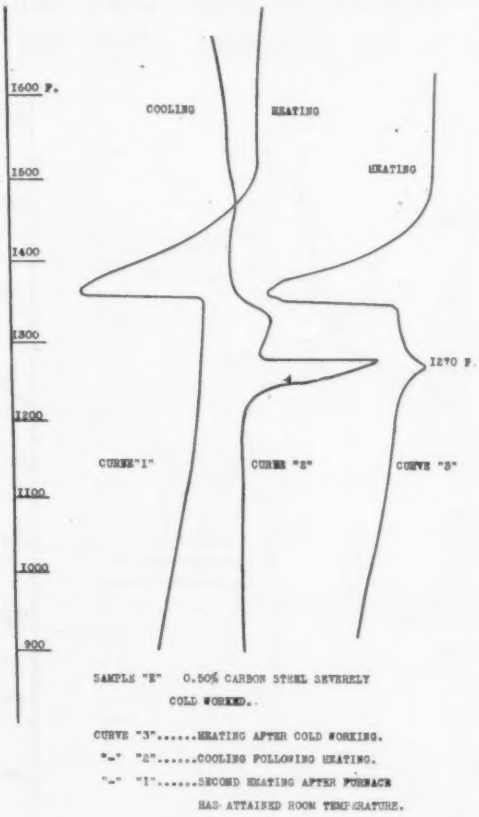

Fig. 2

either the sample or the thermocouple in any way, and the heating curve was again followed. This time the point observed on first heating failed to appear. These observations favored the idea that the observed point is related to the changes taking place on heating a cold-worked metal. For convenience this point will be called "Ax." It disappears and never re-appears after the metal is once heated through the critical range. In order to be sure of the correctness of this deduction a third sample of the same steel was prepared by cold working it, as previously described, but then annealing at 1600 degrees Fahr. before preparing the sample for critical point determination. Fig. 3 shows that no disturbance corresponding to "Ax" could be found. The writer would like to mention here that the curves so far re-

produced, as well as those that are to be shown later, were derived experimentally several times with the same final results.

It seemed advisable to investigate, under similar conditions, the behavior of steels which differed, both in carbon content and in the treatment which they previously received. Carbon

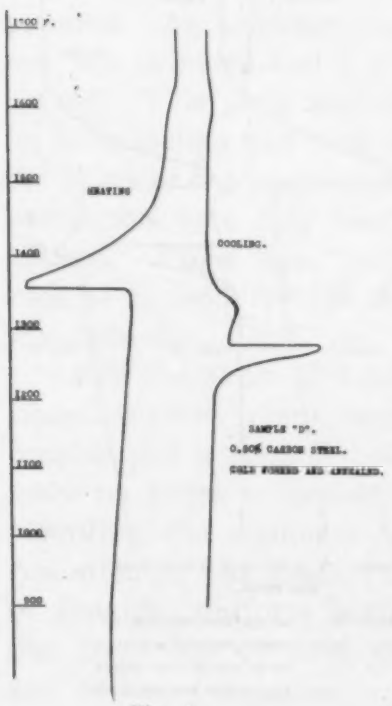

Fig. 3

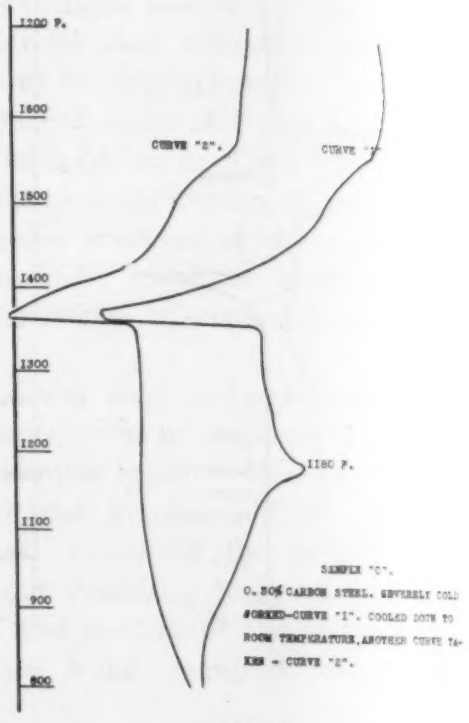

Fig. 4

steel of 0.30 per cent carbon, hot-rolled, was selected for the purpose. A piece of this 0.30 per cent carbon steel was cold-worked from ½ inch round to $\frac{5}{16}$ inch square and the critical point sample was prepared. The curve 1 (Fig. 4) taken from this cold-worked sample shows distinctly a critical point "Ax," which is located at about 1180 degrees Fahr. The cooling curve taken from the same sample (not shown on Fig. 4) showed no corresponding thermal disturbance. Similarly, when the same sample of steel, undisturbed in any way, was again heated up, nothing unusual happened, the heating of the sample proceeding uniformly and smoothly until the ordinary A_1 point was reached. (curve 2, Fig. 4). A sample of the same steel if annealed after cold-working shows no anomalies during the thermal analysis: it can be seen from Fig. 5 that the thermal critical curve of this sample

shows the A_1 point on heating and cooling and probably the combined A_2-A_3 point and that no thermal disturbance of any nature takes place until A_1 is reached.

It is known that certain metals subjected to cold-working

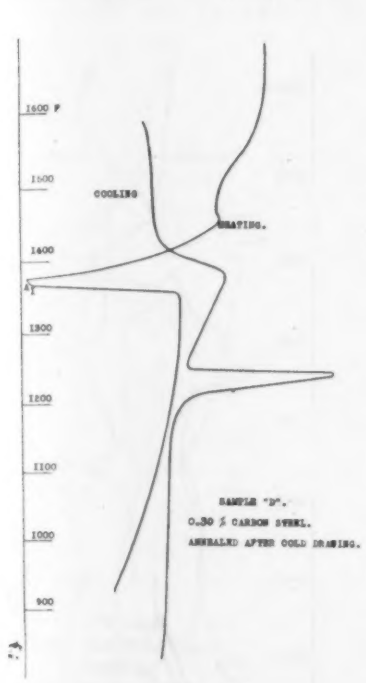

Fig. 5

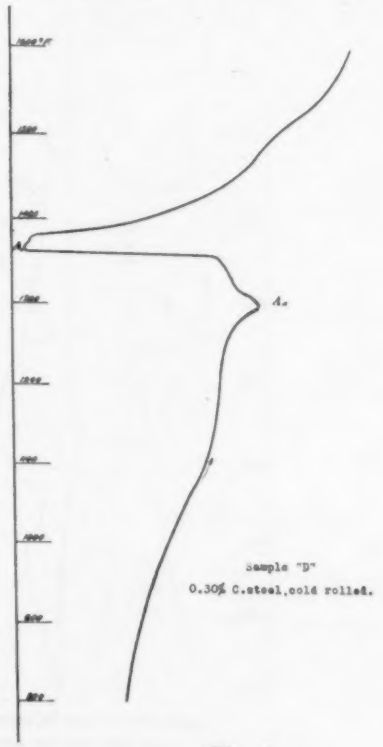

Fig. 6

undergo gradual changes in their properties even at room temperature, if given sufficient time. These gradual changes are believed to be connected with the change in internal energy imparted to metals during cold-working. If the thermal disturbance, described here in cold-worked metals and designated as "Ax," is the manifestation of a certain change in the internal energy only (such a change tends to establish an equilibrium), then in the case of steels cold-worked and then "aged" we could hardly expect to find an "Ax" point. Doctor Sauveur points out quite rightly that this "Ax" point must be closely associated with the germinative temperature (private communication).

A piece of 0.30 per cent carbon steel, cold drawn, was secured. This steel was known to have been "aged" for about six months. After a rather careful investigation it was found that even this steel (Fig. 6) shows a pronounced "Ax" point, although its

position was shifted to about 1300 degrees Fahr. It must be mentioned here that the amount of cold-working given to this steel was unknown. This is important for the reason that if "Ax" point is connected with germinative temperature, then

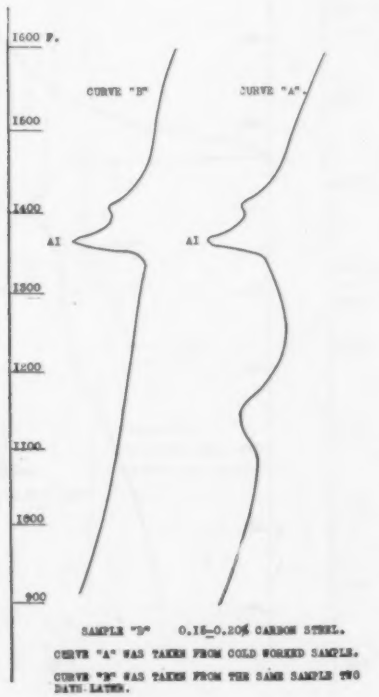

Fig. 7

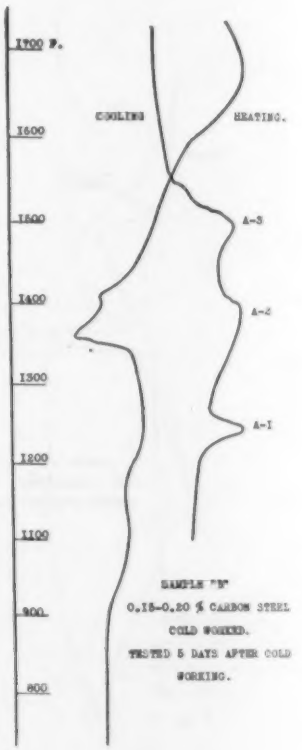

Fig. 8

it also depends on the amount of cold work received. It should be the lower the greater the amount of cold work.

This experiment with 0.30 per cent carbon steel was repeated several times and each time the "Ax" point was observed, though its magnitude and its position on the temperature scale varied somewhat, the magnitude being the greatest when the sample is tested immediately after cold-working.

The presence of the "Ax" point in the case last described indicates either, first, that the effect of imparted internal stresses persists for a long time and is only partially, if at all, obliterated by what is termed "aging"[1] or second, that the observed thermal

[1]Doctor Sauveur writes: ". . . on the assumption that the point is due to a recrystallization of ferrite, aging should have no action at all unless distorted ferrite undergoes a certain amount of spontaneous recrystallization at room temperature, which, of course, is not altogether impossible." (Private communication.)

disturbance ("Ax") is caused by some irreversible alteration in the metal proper, upon heating.

When the piece of 0.15-0.20 per cent carbon steel is similarly cold-worked and tested, the appearance of the "Ax" point is not as marked as in the case of the other samples described

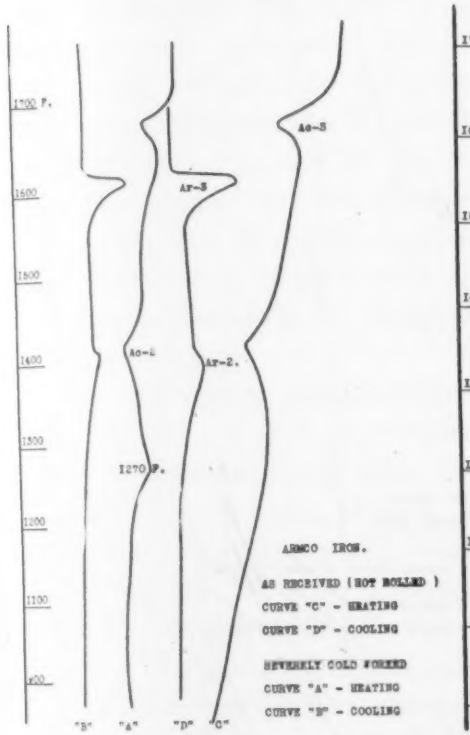

Fig 9

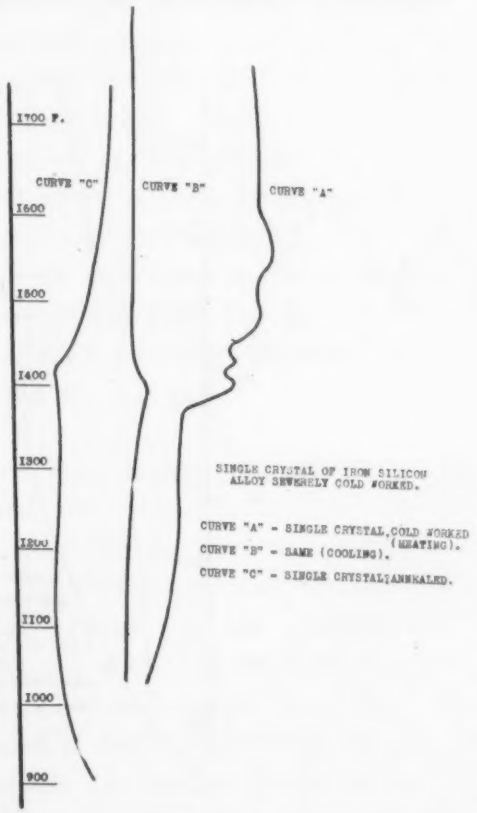

Fig. 10

(Fig. 7); at least it is not as sharp. The uniform heating of the sample goes on until about 1100 degrees Fahr. is reached. Then the difference-thermocouple seems to show a small, rather gradual, absorption of heat followed immediately by a very pronounced evolution of heat. The peak of the heat evolution is not sharp and the thermal change, as was said, proceeds rather gradually. In view of previous work, however, it appears reasonable to regard the peak, which is located at about 1240 degrees Fahr., as the "Ax" point. It matters but little at which temperature we place the peak. The fact remains that the same change as described in the case of steel of higher carbon content does take place in this particular low carbon steel. Curve B (Fig. 7)

shows no abnormalities until the A_1 point is reached; this curve "B" was taken from the same cold-worked sample two days after the first one (curve "A") on which the "Ax" point was found. Neither the sample nor the thermocouple were disturbed in the meantime. Whatever is responsible for the thermal disturbance

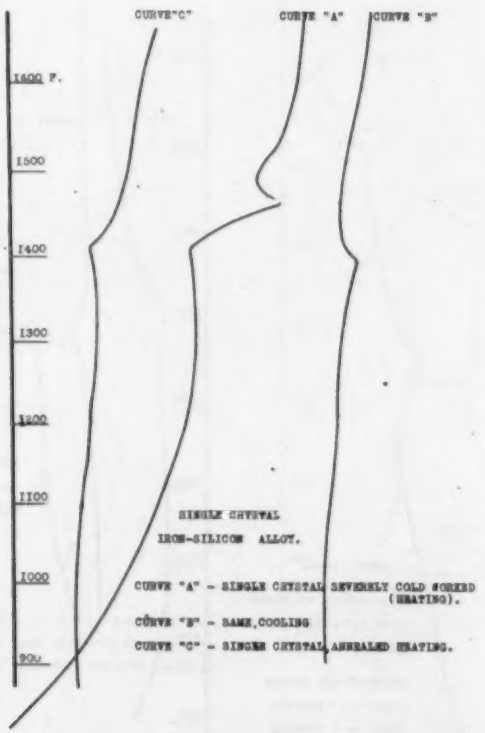

Fig. 11

was completely obliterated during the first heating (curve A) and, consequently, the second heating (curve B) proceeds normally.

If the same 0.15-0.20 per cent carbon steel is investigated some five days after cold working (Fig. 8), the thermal disturbance is still to be observed, but it is not as pronounced as in the case of steel heated immediately after cold working.

Armco iron supplied in the hot-rolled condition has also been subjected to the investigation (Fig. 9). "Hot-rolled" shows naturally no anomalies on either heating or cooling. When however, the same Armco iron is cold-worked in the same way as the rest of the samples previously described, a change in the thermal equilibrium of the sample is observable at about 1270 degrees Fahr.

This change does not re-occur either on cooling or on a second heating following cooling.[2]

It was of interest to the writer to make similar tests on a rather unusual sample consisting of a single crystal of an iron-silicon alloy containing 1.68 per cent silicon. Some single crystals were sufficiently large, especially after cold working, to permit the preparation of samples for the critical point determination. The results are reproduced in Figs. 10 and 11. No thermal disturbances are noticeable (in cold-worked single crystals) below A_2 point, contrary to the case of carbon steels. Immediately, however, following the A_2 point there occurs, relatively speaking, a tremendous change in the thermal equilibrium. This consists in some cases of several evolutions and absorptions of heat (Fig. 10). But the similarity to the carbon steel lies in the fact that this disturbance occurs only during the first heating after cold working. Thereafter it disappears.

To sum up:

1. If metals, from 0.50 per cent carbon steel down to Armco iron (either as cast, hot-rolled or cold-rolled), are worked at room temperature and then subjected to thermal analysis, they all show an evolution of heat, sometimes gradual, sometimes quite sudden; the evolution of heat creates on the critical curve a point similar in every respect to standard critical points, but opposite in sign. It is arbitrarily designated the "Ax" point.

2. The position of the point is not always constant and fixed.

3. It seems quite reasonable to assume that the Ax point indicates both recrystallization and a relief in internal strains.

4. The Ax point is not of the reversible type: it disappears entirely after the first heating of the cold-worked sample. Hence its appearnce must be closely connected with the specific properties imparted to a metal by cold working.

The microscopic investigation followed the thermal analysis and will be described in the same order.

The microstructure of cast 0.50 per cent carbon steel is shown in photomicrograph Fig. 12. It is the ordinary structure of cast steels; very large pearlitic or sorbitic grains are surrounded by heavy ferritic boundaries. It should be noticed that these ferritic boundaries are evidently of the same orientation:

[2] Armco iron was tested accidentally under low sensibility. Should higher sensibility be used the magnitude of the disturbance would be much larger.

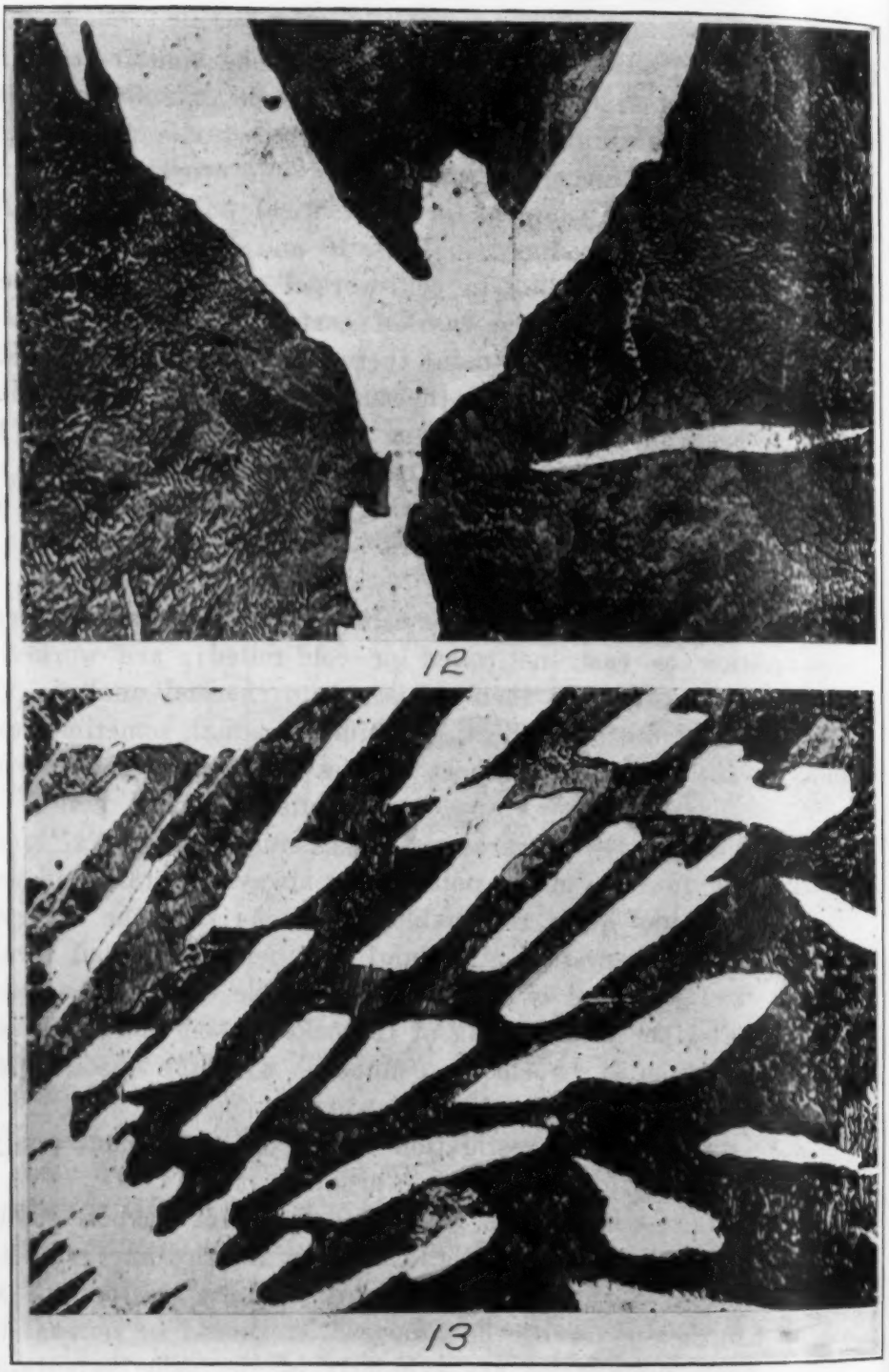

Fig. 12—Cast Steel Having a Carbon Content of 0.50 Per Cent. Etched in Dilute Nitric Acid. 350X. Fig. 13—Cast Steel Cold-Worked. Carbon Content 0.50 Per Cent. Etched in Dilute Nitric Acid. 350X.

they do not contain several small grains. Even deep etching fails to bring out either grain boundaries or different coloration. The presumption is, therefore, that these large and wide ferritic areas contain but one grain. Some of the ferrite, of course, is lodged not only at the grain boundaries, but also within the grain as is seen to a certain extent on the lower part of Fig. 12.

When the steel is cold-worked this last mentioned ferrite takes on an interesting shape. The continuous ferritic bands are broken up, showing what might be termed "deformation by steps." The shape of the grains is peculiar and in a way characteristic. The elongation in one direction is so evident that one could easily tell the direction of cold work (Fig. 13). And yet, each ferritic particle, whether it be a small elongated fragment or a more or less continuous band as is seen in the lower left corner of photomicrograph, Fig. 13, contains only one grain. No boundaries within the ferritic grain can be brought out, even by the most severe etching.

After cold working, one of the pieces of this steel was prepared in the form of the critical point sample and heated to a temperature just below that at which the "Ax" point was expected: such a temperature being determined approximately by the previous experiment. It was found that apparently no change had taken place (Fig. 14). The structure of the sample was much the same as that of the cold-worked material shown in the photomicrograph of Fig. 13: the ferritic areas still possessed directional orientation and consisted of the characteristically shaped but singular grains.

The same sample was then heated up to the point when the "Ax" effect seemed to be entirely completed, this heating being followed by rapid removal from the furnace and cooling in the water. The structure of the sample was now different: it is shown in the photomicrographs Figs. 15, 16 and 17. The shape of the ferritic grains did not change much: it still consisted of elongated shoots, in some places accompanied by smaller fragments of the peculiar shape already described. (See photomicrograph Fig. 16). But every ferritic inclusion now showed a number of distinct boundaries, sub-dividing each large mass of ferrite into a number of much smaller grains. The recrystallization, or in accordance with Dr. Jeffries' nomenclature, grain growth has taken place within the ferrite. It must be indicated at this point that such

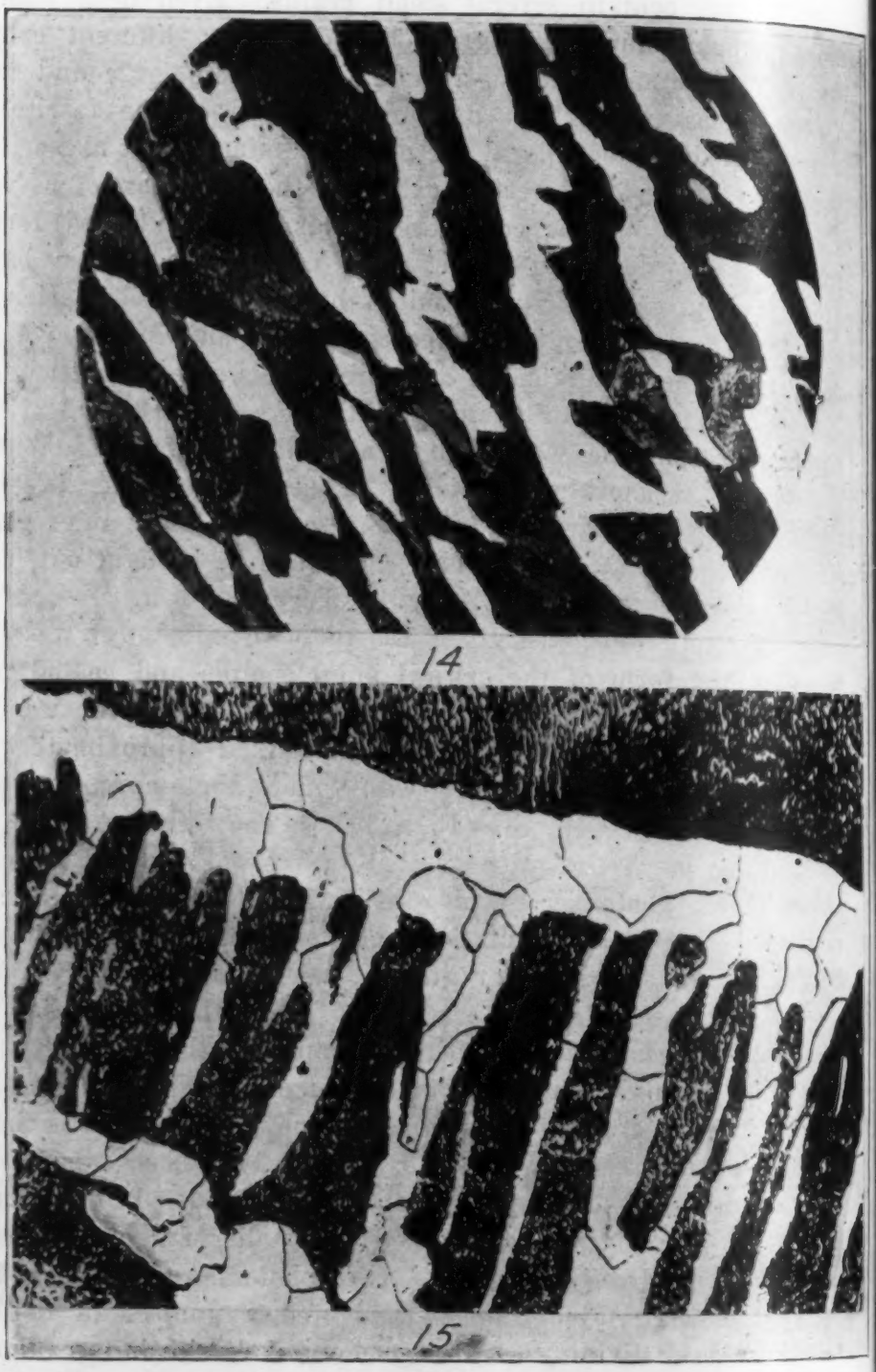

Fig. 14—Cast Steel Cold-Worked. Heated Below Ax Point. Etched in Dilute Nitric Acid. 350X. Fig. 15—Cast Steel Cold-Worked. Heated Above Ax Point. Etched in Dilute Nitric Acid. 350X. Carbon Content 0.50 Per Cent.

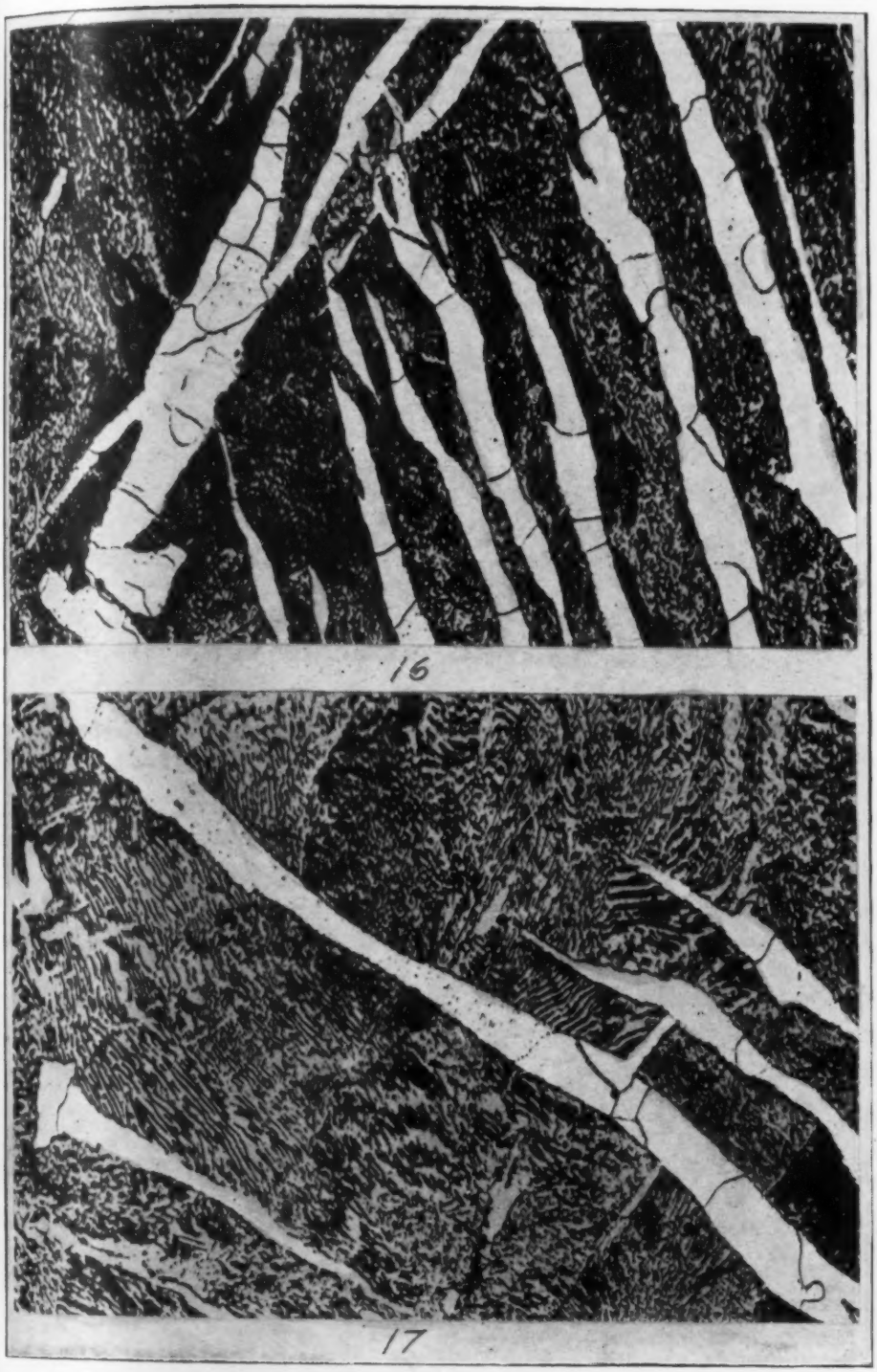

Fig. 16 and 17—Cast Steel, Cold-Worked. Heated Above Ax Point. Etched in Dilute Nitric Acid. 350X. Carbon Content 0.50 Per Cent.

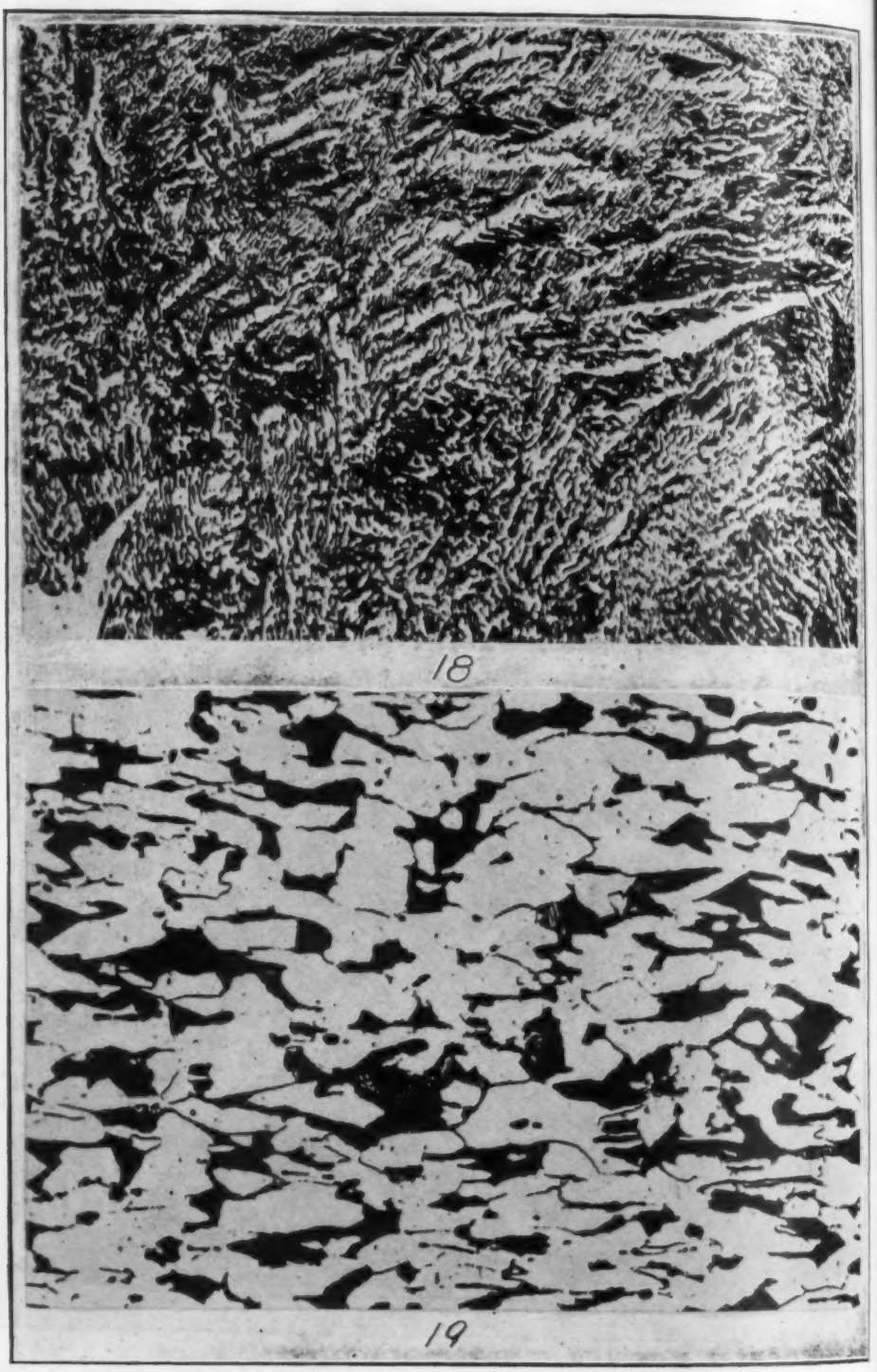

Fig. 18—Distorted Pearlite in Cold-Worked Steel. Etched in Dilute Nitric Acid. 500X.
Fig. 19—Hot-Rolled, 0.30 Per Cent Carbon Steel, Cold-Worked. Etched in Dilute Nitric Acid. 350-X.

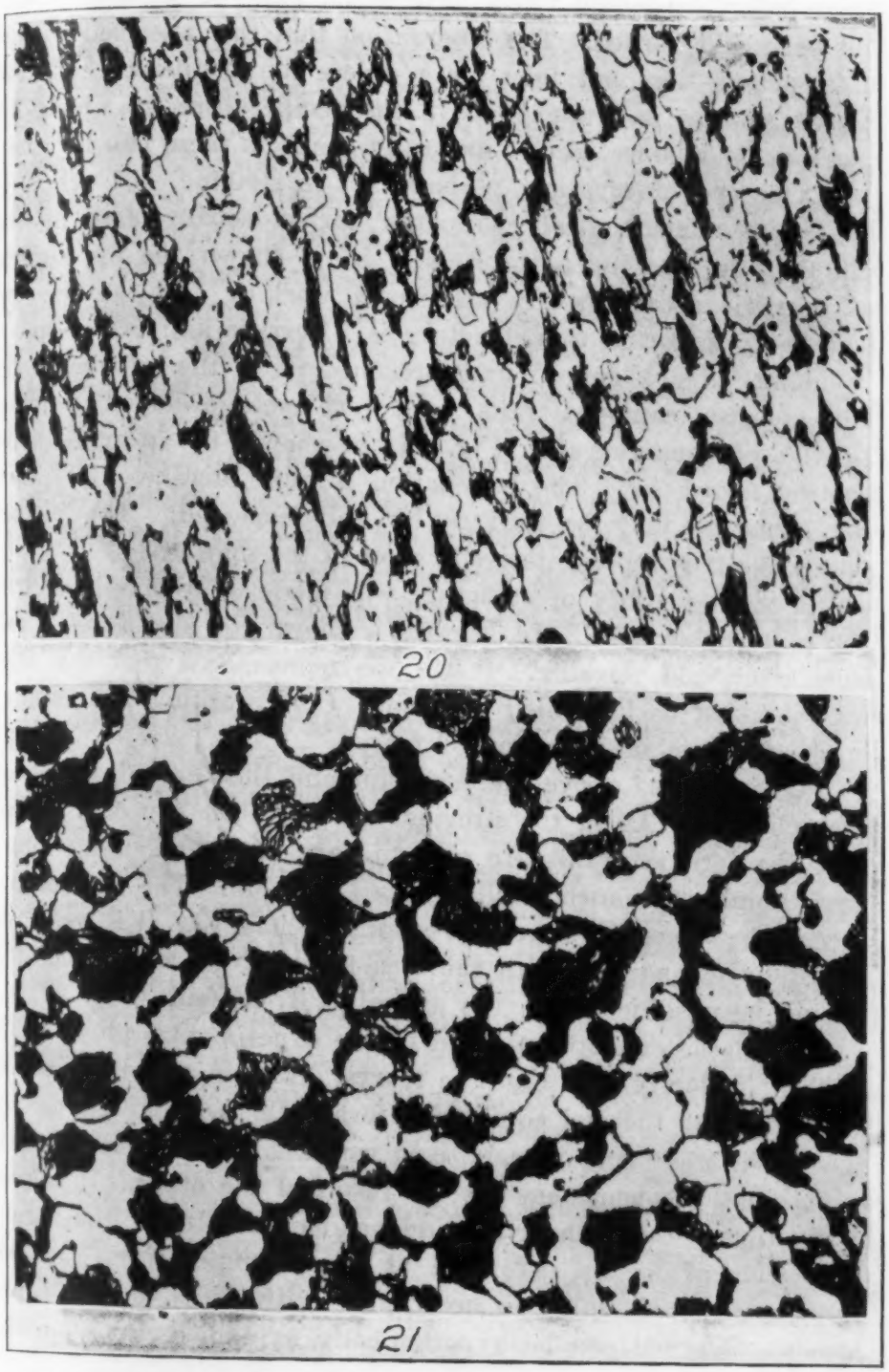

Fig. 20—Hot-Rolled 0.30 Per Cent Carbon Steel, Cold-Worked. Heated Above Ax Point. Etched in Dilute Nitric Acid. 200X. Fig. 21—Hot-Rolled 0.30 Per Cent Carbon Steel, Cold-Worked and Annealed. Etched in Dilute Nitric Acid. 350X.

recrystallization would never have taken place if the sample had not been cold-worked. The observation that the described change in structure does not take place unless the temperature of the heated sample is brought above the temperature at which Ax thermal disturbance occurs, naturally connects these two together.

A second observation, perhaps not so striking, but nevertheless quite evident, deals with the carbon-bearing area of the sample. In photomicrograph Fig. 18 is shown the appearance of pearlitic areas directly after cold working. It can be seen how badly distorted this structure is. Ferritic and even cementitic lamellae are curved and broken. Even the comparatively high power employed fails to reveal well-developed pearlite. In the photomicrograph, Fig. 17, is shown the pearlite after heating above Ax. The lamenation is quite distinct and pearlitic structure may be said to be well-developed. The picture shown is a true representative of most of the sample.

A similar study of structure was made of a sample of 0.30 per cent carbon steel. In Fig. 19 is shown the structure of this steel after cold working. It will be remembered that this steel was obtained as hot-rolled material. Cold working has resulted in the directional elongation of ferrite.

When heated above the Ax point and then cooled, the structure changes. As in the previous case of 0.50 per cent carbon steel the ferritic grains are seen to have been broken up into a large number of much smaller ones (Fig. 20). The general picture of the structure, however, remains unchanged. It is well illustrated by comparison with the structure of the same steel after having been subjected to the annealing treatment (Fig. 21).

From the description given of the experimental phase of the work it is clearly seen that the recrystallization and the observed change in the thermal equilibrium are both to be traced back to the initial treatment, namely, cold working. It is doubtful, however, if either phenomenon is the result of the other. It is more likely that both of them are independent results of the specific properties of metals deformed at room temperature. Yet the fundamental principles, in accordance with which both the phenomena observed can be hypothetically explained, are somewhat related.

The recrystallization of strained or cold-deformed metals is fairly well understood. Cold working of any metal results in the

production of crystalline fragments outlined by the crystallographic planes. On heating, these fragments undergo but small changes until the recrystallization temperature is reached. According to Jeffries, "... changes below recrystallization temperature would be largely in the direction of perfecting crystalline organization at the boundaries between crystal fragments and perhaps in the coalescence of some of the very small fragments."

On reaching recrystallization temperature, the recrystallization proper proceeds by means of some of the grains absorbing the others. That the process consists in "absorption" and not in the formation of entirely new grains with the new nuclei as starting points, is proven by the observed fact that the new grains have the same directional orientation as the crystalline fragments in the cold-deformed samples.

The necessary condition for this process of "absorption" is the straining of different grains to various extents. Such a condition must necessarily exist in the cold-worked metals. The amount of straining received by each individual grain in the large conglomeration of such grains in any given piece of steel depends on the orientation of the grain in relation to the direction in which the cold working is applied. The grains which are the least strained grow at the expense of those that are more severely strained. If we explain the straining in somewhat different terms, we will be able to see more clearly the relation between the phenomenon of recrystallization and the thermal disturbances dscribed above. The formation of the crystalline fragments occurs through gliding or slipping along the surface of the crystalline plane. This gliding or slipping necessitates a loosening of the molecular cohesion in the deformed crystal and a certain amount of work is required to bring about such loosening. This in turn means that the energy content of crystals differently deformed will be different. Summing up, then, recrystallization of deformed metal on heating is made possible because of the different amount of energy stored up in the individual grains through cold working. This conception will perhaps make the rôle of cold working a little clearer.

Let us turn now to the thermal disturbances. It is known that in order to bring about recrystallization in the deformed metal, we need only slight deformation. In the case of all the samples described above, the deformation was quite severe and

must necessarily have resulted in a large amount of energy being stored in the sample as a whole. It is quite reasonable to suppose that only a part of this energy is required to start recrystallization. If such be the case, then the rest of the stored energy can be termed the "free energy" of the sample. The existence of such energy is the reason that so-called "external strains" exist in deformed metals; these strains are relieved by heating the deformed metal to a certain temperature. We may just as well say that by heating we relieve the sample of free energy, and that such a process is most likely to be accompanied by, or result in a change of thermal equilibrium within the sample. The author arrived at this conclusion quite independently from any other work, but was glad to find the confirmation of his views in the recent work of Prof. Gustav Tammann, who even gives a formula for the increase in the energy content in calories per unit volume of the deformed metal.[3]

It is an interesting coincidence that the liberation of the excess energy in the form of heat, described in this article as the "Ax" point, occurs at the same temperature as the recrystallization. It is probable that the mobility of atoms, which is essential to the liberation of excess energy, is also the fundamental factor in the phenomenon of recrystallization. It is planned to test this by further experimentation. The author believes that there is sufficient evidence to state that the liberation of the heat in deformed metals, as observed and described in this article, has as the reason for its appearance the same underlying cause as the recrystallization of deformed metals at low temperatures: namely, the change in the internal energy of the sample by cold working.

The author is indebted to Professor Albert Sauveur and Dr. F. M. Walters for the criticism of the manuscript.

[3]Tammann. A Text Book on Metallography. 1925. p. 129.

STEEL MELTING SESSION—CLEVELAND CONVENTION

The following four papers were presented before the Society Tuesday morning, September 15, 1925. The chairman of this session was Dr. J. A. Mathews, vice-president of the Crucible Steel Company of America, New York City.

PROPORTION OF HEAT TREATED STEEL TO TOTAL PRODUCTION

By C. J. Stark

Abstract

The writer of this article considers the qualitative conception of the steel industry more important than the quantitive. In his discussion he considers a heat treatment any treatment of steel for the specific purpose of effecting certain desired changes in the structure of the material. Among the greatest patrons of the heat treatment of steel are the automobile industries. The railroads have been backward in adopting heat treating of their material, because they did not feel able to pay the price of scientific knowledge and skilled labor, but the heads of their mechanical departments are beginning to show a greater appreciation of the advantages of heat treatment for certain purposes, such as for material going into locomotives and cars. Today approximately three million tons of steel are being heat treated to serve various purposes.

ANOTHER of the important transitions which have marked the course of progress of the American iron and steel industry apparently is in motion. Its final effect upon the industry promises to be far reaching; so much so as to warrant comparison with that which attended the successful introduction of coke as metallurgical fuel or the swingover from the Bessemer to the open hearth as the chief method of steel manufacture. The new stage into which the industry has entered may be termed that of intensive scientific exploitation of the properties and utility of steel for specific application. The exacting needs of our speeded

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up civilization have supplied the driving force to this development.

The quantitative conception of the steel industry which has ruled so long in this country plainly is giving way to the qualitative. For years the chief objective of the steel manufacturer has been production because the needs of the country for common steel have been so large. Apart from rails and a few other products where scientific knowledge has been trained alike on production and performance, tonnage has demanded first consideration. Today, principally through the pioneering of the automobile industry, steel makers have come to realize their function not only is to make good steel, but to follow it through to its ultimate applications and see that it performs its work properly and completely. The automotive engineers have done the metallurgical world a great service by the way in which they have defined their requirements through constant study and research. As a result they represent the only group that has standardized completely in a scientific way its steel necessities and from these has formulated its own set of specifications.

This trend in steel manufacture, from the general to the specific, is illustrated by the recent decision of the United States Steel corporation to build at Chicago a large new plant designed especially for the rolling of alloy steels. This action definitely launches the country's first producer into the manufacture of special steels on a large scale since its operations of the past have had to do almost entirely with ordinary carbon steel.

Development of the science of heat treating has furnished one of the chief factors contributing to the present refinement of application and serviceability of steel. It has helped to make possible many of the great engineering accomplishments of the day. That it has a large and indispensable part to perform in furthering mechanical as well as human progress, is certain. In order that this duty and responsibility may be more clearly outlined and more definitely grasped, economic as well as scientific facts are essential. There is called for an appraisal of the character and magnitude of the present heat treating industry and a precise knowledge as to how its growth corresponds to that in the general demand for steel. For the first time a careful and systematic effort has been made to determine the tonnage of heat treated steel that is being required by main consuming groups

and to show in what manner this application is made. As is necessarily true in all such original efforts, the data are not entirely complete or fully comprehensive. Nevertheless, they establish a good foundation for future elaboration and refinement.

In this discussion heat treatment is considered any treatment of steel for the specific purpose of effecting certain desired changes in the structure of the material, usually by quenching, hardening or tempering. Ordinary preheating and annealing operations are not considered.

One main approach to the total volume of heat treated steel is through the production of alloy steel. In recent years production of this sort, according to official statistics, has approximated 2,000,000 tons per annum, of which more than 95 per cent was in the form of ingots and the remainder of castings. However, this includes probably 1,000,000 tons of copper-bearing steel for rust-resisting and protective purposes, which is not heat treated. The remainder, about 1,000,000 tons, is heat treated.

The automobile industry has proved itself the greatest patron of heat treatment of steel, as it has also of alloy steel. Much of this development may properly be attributed to the application of advanced scientific methods and research on the part of automotive engineers and metallurgists. It is doubtful whether in any major industrial field has greater scientific effort along practical lines been devoted to the improvement of steel or to the determination of its utility for various purposes. Last year the automotive industry, taken as a whole, consumed approximately 3,200,000 gross tons of rolled steel. As much, if not more, tonnage will be required this year. Of this total probably 15 to 20 per cent was of alloy quality. The percentage varies in accordance with the individual manufacturer. On this general basis, estimated, the automotive industry today is using 50 to 60 per cent of all the commercial alloy steel produced. Most of the steel now being consumed by the automotive industry, whether of carbon or alloy character, is heat treated.

Because of their large needs and the exacting service their equipment and tracks are subjected to, the railroads might be expected to be the source of greatest demand for heat treated material. Of all the main consuming groups, the railroads take the largest fraction of the output of the steel mills, this amounting to 27.5 per cent in 1924 and something over 30 per cent in

1923. In gross amount this was approximately 7,395,000 gross tons in 1924 and 9,277,000 gross tons in 1923. The relatively small amount of this tonnage that is heat treated commands attention. The railroads are backward in adopting heat treating of their material largely because of the need of a scientific knowledge and skilled labor to properly meet their requirements. Apparently they feel they cannot afford to pay the price or to secure service on the scale that would be demanded by their operations. Following this policy, the railroads do a lot of annealing and find it much easier to handle work under a forge or hammer.

However, the heads of mechanical departments of the railroads are showing a greater appreciation of the advantages of heat treatment for certain purposes. Today a great deal more heat treated material is going into locomotives and cars than ever before. The average locomotive contains about 45,000 pounds of heat treated steel exclusively of accessories, such as air pumps, air brake apparatus, injectors, etc. The parts heat treated include frames, springs, side rods, piston rods and link motion details. More and more the railroads are using annealed carbon vanadium steel for side rods, piston rods, etc., which is supplanting carbon steel. On the basis of normal construction 40,000 to 50,000 tons of heat treated material are used in locomotives annually.

In passenger and freight cars, the amount of heat treated steel aside from springs is negligible. Speaking generally, car axles are not heat treated. Car castings are annealed but this is regarded as nothing more than a normalizing process. Some heat treatment of special parts also is being done but this involves very little tonnage. Taking an average of 125,000 freight and passenger cars built per year, this would mean, it is estimated, heat treatment to the extent of approximately 40,000 tons. Heat treatment of mine car axles is in growing adoption and thousands of these parts are going to this industry each year.

As to track fastenings, practically all track bolts and angle bars are oil quenched. In recent years production of angle bars has run approximately 175,000 gross tons per annum. It is estimated that track bolts represent 5 per cent of the total tonnage of all bolts manufactured. This would indicate that something like 50,000 tons of track bolts are produced each year. Of frogs,

switching points, etc., probably 20 to 25 per cent is heat treated, this comprising all the manganese steel. The open hearth material, which accounts for 75 per cent of the total, is not treated.

The electric railway field is a large user relatively of heat treated steel. One estimate places the total between 85,000 and 90,000 tons, comprising axles, gears, pinions, truck springs, upholstery and miscellaneous springs. On this basis at least 20 per cent of the total steel requirements of the electric railway industry calls for heat treated steel, mainly for car construction.

Of more than 1,000,000 tons of steel going into nuts, bolts and rivet manufacture each year, the largest fraction is subjected to heat treatment in some form. One authority places this proportion as high as 80 per cent. The heating of bolts in general falls into three classes. The first group includes those which are heated primarily for forging or hot heading. The second represents cold-headed bolts and rivets which are heat treated to relieve the strains caused by cold heading. Probably 25 to 35 per cent of the total tonnage of bolts comes within this class. The third group consists of bolts which are given more careful heat treatment for improving their physical qualities, such as track bolts, which are nearly all high carbon; bolts for automobiles and, to a slight extent, other purposes, which are high carbon or alloy steel; and third, low carbon steel bolts heat treated by special process.

Practically no heat treated steel is used in building construction but in the case of bridge work and particularly long spans where the parts are pin connected, the eye bars are heat treated. The annual consumption of these heat treated eye bars is approximately 15,000 tons. In addition there is a nominal tonnage of heat treated pins for this type of bridge construction, which more properly might be classed as machine parts. The only other material used in the structural steel industry that is heat treated are the parts of machinery used in draw span bridges, which more properly could be included in the machinery group. In the case of eye bars this material is made from two specifications. One calls for an elastic limit of 50,000 pounds per square inch and the other for 75,000 pounds per square inch. These bars are of carbon steel quality.

Approximately 200,000 tons of steel are used by the shipbuilding industry and about 7 per cent or 14,000 tons is heat

treated. This includes the propellers of steel castings, line and tail shafting, engine shafting, piston rods, connecting rods, valve stems, rotors and blading of turbines where of steel, other steel parts of machinery and parts of similar auxiliary machinery. Anchor chain, if of cast steel, is so treated. Perhaps 80 per cent of the chain over 1½-inch diameter now is of cast steel.

It is difficult to fix definitely the extent of heat treatment in the construction of machine tools, small tools and miscellaneous machinery. One authority states that 40 per cent of the total amount of steel going into machinery and machine tool production and 95 per cent of that going into small tools is heat treated. If this be an accurate statement, probably 300,000 to 350,000 tons of steel going into machinery annually are heat treated in process of manufacture. Virtually all of the steel used in the manufacture of saws is heat treated. In point of weight it is estimated this would be approximately 30,000 tons per year. One prominent saw manufacturer is reported to have recently obtained a basic patent for welding high speed steel to soft steel and now is using this process exclusively in the case of machine knives with a considerable saving in the cost of steel and in that of heat treating.

One manufacturer of crawler-type cranes now is heat treating something like 60 separate parts or 250 pieces per unit in the building of this equipment. In this way it is stated 10 to 20 per cent is added to the wearing quality of these units.

A recent development in heat treating is its application to plow beams. The shares are attached to the beam. It is important, therefore, that the latter be fortified against bending or breaking. Formerly a rolled flat section was used. The beams on all plows used in connection with tractors are high carbon steel, heat treated. This represents a weight of probably 5000 tons per annum.

Other main sources of normal steel consumption which have not been touched upon include oil, gas and water requirements, mining and lumbering. All the heat treatment requirements of the mining and lumbering industries are covered under machinery with a few exceptions. The same applies to oil, water and gas activities except to drilling tools which are heat treated on the ground.

The army and the navy are important users of heat treated

material though not in a tonnage way, for ordnance, airplanes, projectiles, armor plate, protective decking, etc.

Summarized, it may be said that approximately 3,000,000 to 3,500,000 tons of steel are being scientifically heat treated annually to serve various economic or mechanical purposes. The automobile industry has furnished by far the field of greatest progress; that of the railroads, the least. This points the direction in which the industry may look for sound future expansion.

What heat treating ultimately may be called upon to contribute to the cause of aerial navigation in this country cannot be foretold now. It will require no specialized development of the science, however, to meet a large demand from this quarter, since heat treatment already is being widely used to insure great physical strength at minimum weight of material. Whatever form the growth of air navigation may take, it is destined to mean a further notable addition to the scope and usefulness of heat treating.

The second paper of this series begins on the next page.

ACID OPEN HEARTH STEEL MELTING PRACTICE

By Radclyffe Furness

Abstract

In this paper the author outlines briefly the characteristics of the acid open hearth furnace, and gives the contributing cause of the superiority of acid open hearth steel over the basic.

The melting charge is discussed and methods given for controlling the elements in the bath, as well as the proper time to make the additions.

The addition of ore to the bath is considered and the author gives the proper conditions of the bath to obtain satisfactory results from oring the heat.

Acid open hearth slags are discussed; consideration is given to the temperature of the bath, iron and manganese oxide being present. The fluidity of the slag is discussed.

The author emphasizes the importance of the proper "condition" of the bath, stating that this has a great influence on the defects which may appear in the finished product, such as "flakes."

IN writing this paper, the author has endeavored to use as few formulas and technical terms as possible. If, in following this practice, some statements are made, which are theoretically open to discussion, I beg that this be overlooked, provided they express the general idea.

It has been my good fortune to have been connected with the melting department of the plant of the Midvale Company at Nicetown since June, 1891, and, when first coming to the plant, to have worked under Peter McAnally, who was one of the first of the two melters in Midvale working under Charles A. Brinley, while he was putting the open hearth furnace in this plant on its feet in 1872 and 1873.

Although the acid open hearth furnace in Midvale started in 1871, it does not seem to have accomplished anything worth mentioning until 1872, when it was taken in hand by Mr. Brinley.

The author, Radclyffe Furness, is superintendent of the melting and forge department, Midvale Co., Nicetown, Philadelphia.

Following Mr. Brinley came R. W. Davenport and J. K. Griffith, in charge of the open hearth department until about 1889, when Mr. McAnally was put in charge. I mention this bit of history to point out the good fortune which I had in working with a man whose experience went back to 1872, and who had profited by working with the others mentioned above; also to point out that from 1872 up to date, the connecting links in experience at Midvale, back to 1872, consist of only two men, Mr. McAnally and myself. Thus there is small chance of any good practice being lost.

The acid open hearth process, as we now use it at Midvale, is an evolution of the ideas handed down from the men just mentioned, and added to by those subsequently in charge of the melting department. The little difference between the process thus evolved, and that used in other plants in this country, France, Belgium, Germany and England, is of great interest; also, how carefully those in charge of the acid open hearth plants are striving to obtain the same results which we are all striving for at Midvale and how close the standard practices have become.

I shall not attempt to explain or discuss open hearth design, which would constitute a paper in itself, but state that the acid furnace is an open hearth furnace, the walls and roof of which are built of silica brick, and the hearth of silica sand of approximately 98 per cent silica. This silica bottom so happens to be the greatest contributing cause to the superiority of the acid open hearth steel over the basic product. The hearth must be thoroughly sintered together, or set, before any charge is introduced into the furnace. The depth of the bath which is melted on this hearth is a matter of importance, and should be varied, depending upon the purpose for which the furnace is used, a shallow bath for speed, a reasonably deep bath for quality; naturally a happy medium is the best.

In making acid open hearth steel, it must be borne in mind that this process does not remove any phosphorus or sulphur. Therefore, one must provide such a charge as contains less phosphorus than one desires in the finished product, and sulphur sufficiently low to take care of the pick-up which is bound to occur when one uses producer gas, oil, or any fuel which carries a noticeable amount of this element.

The carbon should be such that, when the charge is melted, the content of the molten charge will be well above the carbon

that one wishes to obtain in their finished product. It is desirable to have a noticeable amount of manganese present in the initial charge—approximately from 1.00 to 1.75 per cent, and silicon (about ½ of 1 per cent). While this is not absolutely necessary, it is desirable, because the presence of these elements in the original charge prevents the bath from containing too much iron oxide when melted, as they reduce the oxides to iron; also, the oxidation of these elements, as the charge melts, puts heat into the bath as fast as formed, and continues after the charge is melted, until the manganese and silicon have been reduced to a minimum.

My experience has been that, if the furnace is properly handled, it makes little or no difference in what form the carbon, manganese and silicon mentioned above are introduced into the charge. The carbon may be in the form of some ferro alloy, or else as coal, charcoal, etc., and the manganese and silicon as ferro alloys. In some plants it is the practice to use only pig iron and scrap; in others, a much less amount of pig iron, making up the difference in carbon with charcoal, coal, etc. The pig iron used may be either sand or chilled cast and should have a fairly high manganese content, so that this content together with the amount of these elements in the remainder of the charge make up the manganese and silicon desired in the whole. The scrap should be of good quality, not too fine or small, as fine material tends to oxidize when melting. The oxide thus formed will cut the sand bottom of the furnace and aid in choking up the checkers. Furthermore, light and fine scrap have a tendency to fuse together in one mass and delay the melting of the charge.

The charge should be thoroughly melted, and given a short time in which to increase its temperature. The oxidation of manganese and silicon, as mentioned above, help this increase in temperature. If little or no manganese and silicon are present, it will take longer for the bath to get hot, or, as is generally said, "in condition to take ore." After the bath has picked up temperature, ore is added to reduce the carbon to such a point that one may make the desired addition of ferro alloys, without running the total carbon content of the bath too high. If the manganese and silicon content in the bath, when melted, is small, it will then take the bath longer to get "in condition to take ore," both from lack of temperature, and from the fact that there is so much oxide of iron present, that one does not know the percentage of

carbon on which one can count, and, therefore, it is necessary to wait until the bath has come "in condition to take ore," before beginning to reduce this carbon.

If the bath, when melted, does not show the carbon high, noticeably higher than that desired in the finished product, carbon must then be added in the form of pig iron or spiegeleisen. This is an expensive practice, and one to be avoided, as a much greater quantity of carbon will have to be added at this stage, before the bath has been put in proper condition, than would have been added if it had been put in with the original charge.

The addition of ore to the bath is a matter of great importance and requires experience and judgment as to the total amount which should be added, and the rate at which the amount may be added. Naturally, it is desirable to get into the bath sufficient ore to reduce the carbon to the point desired as quickly as possible, so as to "make time" on the heat, thus increasing the production per hour. If, however, too much ore is added, one loses time and runs up expense by the necessity of having to add carbon to bring the carbon content up to that desired. Therefore, the addition of ore is important, and greatest care should be used to get in exactly the right amount, at the proper rate, to bring the carbon to the point desired, when all of this ore has been reduced, and the resultant gas boiled off. This point is spoken of as "condition," and on the "condition" of the bath at this point depends the success or failure of the heat.

Whether all acid open hearth melters recognize this fact or not, nevertheless it remains true that the success or failure of their product depends upon the constancy with which they bring all heats of the same composition to a standard "condition" before making their final additions. This "condition" is a phenomenon that one, after watching an acid open hearth furnace for a short period of time, cannot miss, as the bath, from boiling violently, and frothing like a glass of charged water, when first poured, becomes flat and quiet, with bubbles breaking here and there; or, again, it is like a beaker of water when violently boiled, or when just boiling, and now and then giving off a bubble.

Slags

So far I have made no mention of the slag, but feel that now

is the time to take this matter up. Therefore, we shall go back to the time that the charge is first melted. At this stage the temperature of the bath is comparatively low, and there is, unless one is working with an extraordinary furnace, an excess of iron oxide in the slag, which is black and generally "dirty" in appearance. Before ore is added this condition must be improved by reducing the amount of oxide in the slag, otherwise the bath would not be "in condition to take ore," and one could not tell at what rate to proceed with the addition of ore. This improvement in the slag is shown by the change in color from dark to light and can be brought about by waiting until the temperature of the bath has increased and the iron oxide in the slag reduced by the carbon present in the bath, or can be hastened by small additions of carbon in the form of coal. Limestone also should be added, this acting as a flux and making a more fluid slag, the carbon, of course, reducing the iron oxide and throwing back the iron thus reduced into the bath. The slag will then become light in color, ranging from a light brown through bluish yellow to white. The varying colors depend upon the amount of manganese present in the original charge, which is present in the slag as manganese oxide. The exact condition as to the appearance of the slag at each stage cannot be fixed by one open hearth man for another, but a standard must be fixed by each man for himself for each grade of steel which he is manufacturing. The color of the slag, if properly watched, is an indicator of "condition," a dark color showing poor "condition" and a light color showing good "condition."

I cannot emphasize too strongly the importance of the phenomenon known as "condition," as the degree of "condition" has a great influence on the defects which may appear in the finished product, such as "flakes." "Condition" is the appearance of the bath at the time when violent boiling has ceased (the boiling being due to the oxidation of the carbon by the iron oxide formed when melting or added to the bath in the form of ore), and when the silicon content of the bath increases *due to silica in the slag being reduced to silicon and going into the metal.*

It is unnecessary to discuss whether the carbon, in the presence of iron, reduces the silicon from the silica in the slag, or whether the iron reduces the silica. The fact that *silicon is reduced,* and goes into the metal, thus showing that a great por-

tion of the oxides and contained gases must have been removed, is sufficient. Nor is it necessary to discuss the percentage of silicon that should be reduced.

When "condition" first shows, then silicon should be added in the form of ferrosilicon. This further stops the oxidation of the carbon, and holds the content, so that the carbon in a test, taken out just before the addition of the ferrosilicon, may be determined by the laboratory, thus giving the actual carbon content in the bath. Based upon this determination the final additions are made to the bath so as to obtain the carbon content desired in the finished steel. Since the amount of silicon and manganese desired in the finished steel is always fixed by a melting specification, and since manganese and silicon are added in the form of ferromanganese and ferrosilicon, the bath must come to condition at such a carbon content as to allow for the carbon contained in the ferro alloys, and the total should only slightly exceed that desired in the finished product.

The degree of "condition" which should be maintained is a matter of experience and judgment, and each one must determine for himself the condition of each grade of steel which gives him the best results at the least cost, and hold this condition as standard. Different open hearth superintendents demand different degrees of "condition." In fact, I have known some who took the chance of never getting the bath "in condition," but when they judged the carbon to have reached the point from which they thought they could build up to their final result, they would add a large amount of solidifier, silicon, manganese, aluminum, etc., or a mixture of all. I have known others who went to such an extreme that they waited until the bath began to get "in condition," then removed all the slag and remade a slag from clay, sand and ground coke or charcoal, covering the bath with this mixture. When a time was reached where there was little or no change in the bath from hour to hour in the carbon content, the final additions of ferromanganese and ferrosilicon were made, little or no silicon being necessary, as sufficient was reduced from the slag.

The first practice I consider to be bad and dangerous, as one cannot judge satisfactorily the exact condition of the bath when rapid changes in composition are taking place, due to violent action and reactions. The second practice I consider overcautious

and expensive, as too much time is taken up in making a heat. When following this practice, heats take from eighteen to twenty-four hours. It is impossible for one to determine or state for another exactly the condition that should be reached, but each one must fix for himself a standard condition for each grade of steel, and hold on to this like grim death until he is thoroughly satisfied that he should change to another standard.

Since the acid open hearth melter has the advantage of having a well marked condition which appears in the bath due to the fact that the furnace has a sand hearth, and since the element which causes this condition also tends to degassify and deoxidize the bath; and if he is a person of reasonable intelligence, he will shortly, for each grade of steel which he is manufacturing, have a fixed degree of "condition" to work to. It is, therefore, evident that he has a better chance of producing more frequently a more deoxidized steel than has the basic open hearth man, who has no such phenomenon as the reduction of silicon to guide him. This, to my mind, is the greatest reason for preferring, for high duty, acid open hearth steel rather than basic; namely, the greater certainty of getting a thoroughly deoxidized steel.

In the practice which I have been describing, I have assumed that an ordinary carbon steel is being manufactured. The principles laid down hold good for any alloy steels which are being made. One may safely state that in making alloy steel, it is always desirable to get the alloy into the charge as early in the operation as possible. Of course, I do not mean at the risk of losing the alloy. For example, nickel is best added with the first charge, a test taken out, and nickel determined as soon as the charge is melted. On this determination a correction may be added, bringing the nickel up to the amount desired in the finished product. Chromium is best added in the form of ferrochromium after the bath is "in condition," after ferrosilicon, but before the ferromanganese. For, if chromium had been added in the first charge, a large percentage of the total amount would have been oxidized and gone into the slag. If we follow the rule that the alloys should be added as early as possible, without danger of loss of the alloy, we are following, I believe, the best practice.

Additions may be made in the ladle perfectly satisfactorily, but on the whole, I consider it desirable to avoid this practice as

far as possible, as we never can tell what condition may be upset or established, and the metal is not given a fair chance to clear and adjust itself.

I have said nothing about the use of either titanium or aluminum, nor do I feel it advisable to enter into a discussion of their merits and demerits. Suffice it to say that conditions may arise where additions of these elements are not only desirable, but absolutely necessary. But, in my opinion, it is a safe rule to use as little of these elements as possible, since, to be effective, they must be added in the ladle, and never to use either where the product is to be subject to transverse tests. The use of these elements is again a case which should be governed by one's experience with each grade of material which one is manufacturing.

Considering the steel itself, made in the acid open hearth furnace from conditions mentioned above, one would expect to find a steel more free from oxides and gases than one would find in a steel of similar composition produced by the basic process. Again, in the acid open hearth process, the metal, on account of the thinner blanket of slag, can be made much hotter. Therefore, all reactions are hastened, and the metal is given a better chance of clearing itself, both of slag and dissolved oxides. If many samples of the two steels are examined under the microscope, it will be found that one's expectations are realized; namely, that the acid steel is the cleaner of the two. Further, it is a characteristic of the acid steel that the crystallization from the fluid to the solid produces much smaller crystals than in basic steel. I have never been able to explain this fact to my entire satisfaction, but believe that it is probably due to the acid steel being the cleaner of the two and have been guided accordingly.

In addition, acid steel seems to be much more "closely knit," or cohesive than basic, less likely to show slips or slides between crystal faces. One would, therefore, expect that "ingotism" or ingot characteristics in a sample taken from an ingot without any work or heat treatment, other than the cooling in the mold from the fluid to the solid, could more readily be broken up, and in addition a better grade of grain refinement obtained in an acid steel sample than a basic. This is a fact, and while it is only with the greatest difficulty that samples cut from large basic ingots can be grain refined by treatment only, and the "ingotism" dis-

solved, this can be done with ease in an acid sample. I also know that this holds good in grain-refining ingots before forging, but I am not prepared to say that after the material has been worked and forged, the acid steel would respond to treatment more readily than the basic. In fact, I have never found any indication of this, but I do know that, since the ingot crystals in the acid may be more readily broken up by heat treatment, therefore it can be more readily dissolved when heating for forging, and one must be less likely to have slips or slides, due to undissolved crystals, in acid material than in basic. The contention that the acid steel is less likely to show defects which are the result of either poor "condition" or "ingotism" which has not been thoroughly eliminated by treatment or work is borne out by the far greater frequency and ease with which satisfactory transverse test bars can be obtained in acid steel forgings than in forgings made of basic material.

Written Discussion:—By W. H. White, U. S. Naval Gun Factory, Washington, D. C.

The author has a very interesting paper and it is known that in his plant many tons of high grade acid steel have been manufactured, "high grade" because physical results measure quality and most of his steel has required such a test.

The superiority of acid open hearth steel over basic open hearth steel is not entirely due to the natural silica bottom and the resulting chemical reactions of the slag from which it is claimed a nascent silicon pick-up is accomplished. When operating an acid unit it is known that a certain high grade scrap must be had to begin with; this in itself is the beginning of a better heat of steel. If the chemistry of the acid process would allow a charge of the poor variety such as is used in many basic furnaces, the reduction of nascent silicon from the silica of the slag would have to be accomplished on the charging platform, as this is where the heat would be after melt down.

Many tons of high grade basic carbon and alloy steel are being made in this country today and the automobile industry has made the greatest demand for better basic steels. The "melt 'em down," "get 'em hot," "knock 'em out" type of melter is being replaced by the man who watches his charge, slag and furnace, knows the chemistry of his steel and slag and duplicates conditions because metallurgical history has convinced him that results are consistently obtained by standardized melting practice. It is believed the same study and thought can be made of basic slags that is being made of acid slags, for "we do not make steel, we make slag," and if the slag condition is correct the result will be good steel. In our plant an acid slag which has more than a total of 35 per cent manganese and

iron taken together puts this particular heat in a questionable status; this figure has been arrived at as a result of a study of slag color and condition and a close analysis of many heats. Slags containing over this amount of iron and manganese did not furnish the characteristic pea green color upon chilling and breaking; they were dull gray on the surface and always associated with a more or less wild heat. The ideal acid slag is pea green upon chilling and breaking, shiny and black on the surface, very gummy when hot, and brittle when cold. After Mr. DeMare's paper, published in the *Iron Age* of June 3, 1920, we made many heats following general good acid practice and the silicon pick up was recorded. Very few heats gave more than 0.05 or 0.06 of 1 per cent silicon increase; this is not sufficient to improve the quality of a heat with a doubtful record or one that has not shown a green slag 30 minutes after melt down; in other words, it is more important that the charge be physically and chemically right for any heat so that for a heat to finish 0.25 per cent carbon on melt down of at least 75 points will be obtained and also a green slag at least 30 minutes later. This is considered more conducive to a good heat than depending upon a nascent silicon pick up to improve a heat inherently bad through the character or make-up of the charge.

The picking up of any considerable amount of silicon in a low carbon heat is at best very difficult and can only be accomplished by obtaining a neutral slag together with a very high temperature. With increasing carbon content, this reaction is much more pronounced, probably due to the lower melting point of the higher carbon material and the tendency of the slag to neutralize itself with greater ease and to permit the reduction of silicon from the silica of the slag.

It will be noted from the log attached that a silicon pick up of 0.06 points was not obtained until after 100 pounds of 80 per cent ferromanganese had been added to the heat, thus entirely killing it prior to tapping; it will also be noted that the heat melted 0.79 per cent carbon and the first slag test taken right after melt down was green. The word "condition" is very appropriate and the occurring of this "condition" at the proper carbon content for a go-ahead with as little doctoring as possible makes for good practice. If too much light and rusty scrap and not enough pig is charged, no silicon pick up can be obtained and no "condition" will occur from a natural clean working heat. It is not reasonable to believe that a few hundredths of one per cent silicon, if such did occur in an ill-working heat, would clear its record. I believe that most good heats are made before they are charged in the furnace by the selection of the right kind and amount of scrap and pig iron and this applies to all grades of steel and methods of manufacture.

It is our practice to make no ladle additions, even aluminum, when required, being added in the furnace just before tapping. Due to slow rates of solution and the short period of time the steel is in the ladle, thorough dissemination of ladle additions is questionable. The paper states that no sulphur can be removed, but if a high manganese content is in the initial charge a sulphur pick up can be avoided and at times a slight reduction can be made.

In regard to "flakes," no two writers have given the same reason for

this defect occurring in steel, but after fighting it for a year in ordnance steels with both basic and acid furnaces we find it exists in the ingot before it leaves the steel-making plant, and the forging and treatment department cannot eliminate it or even improve a heat of steel wherein it exists. Successful bars have been taken from lucky spots of the forging but upon machining the little cracks show up. Many tons of steel being made today would show this defect if transverse bars were pulled on them. To make steel free from "flake" no formula can be given; it requires real talent. The use of good material, proper furnace practice, correct teeming and proper steel temperatures go a long way to keep us on the right track.

Heat No. A-113
Open Hearth — Carbon Casting Heat — October 17, 1924

Time		
	Charge, total	38,500 pounds
	Carbon Scrap	7,500 pounds
	Pig Iron	11,500 pounds
	Carbon Scrap	9,300 pounds
	Carbon Shavings	6,200 pounds
	Carbon Shavings	4,000 pounds
3:00	Started charging	
4:15	*Charged 80%* manganese	*400 pounds*
6:00	Finished charging	
8:00	Burners shifted every twenty minutes	
8:30	Melted down	
	Test for *C. 0.79*, P. 0.045, Ni. 0.47, *Slag green* on melter's test	
8:55	Test for C. 0.74, Slag green on melter's test	
9:10	Test for C. 0.73, Slag green on melter's test	
9:25	Test for C. 0.70, Slag green on melter's test	
9:30	Furnace down, oil off	
9:40	Furnace on, off 10 minutes	
9:50	Charged ore	200 pounds
10:10	Test for C. 0.58, Slag green on melter's test	
10:15	Charged ore	200 pounds
10:40	Test for C. 0.50, Slag green on melter's test	
10:55	Charged ore	100 pounds
11:10	Test for C. 0.38, Slag green on melter's test	
11:40	Test for C. 0.32, Slag green on melter's test	
12:15	Test for C. 0.25, Slag green on melter's test	
	Heat being held for Sil. reduction	
12:45	Test for C. 0.24, Slag green on melter's test	
1:00 P. M.	*Test 0.03 Silicon*	
1:15	Test for C. 0.21, Slag green on melter's test	
	Charged lime	60 pounds
1:32	*Test 0.03 Silicon*	
1:35	Test 80% Mn.	100 pounds
1:40	*Test 0.09 Silicon*	
1:41	Hot test, 28 seconds	
1:56	Hot test, 27½ seconds	
	Charged 50% silicon	230 pounds
2:06	Charged 80% managanese	330 pounds
2:09	Rabbled	
2:10	Hot test, 16 seconds, Film top	
2:11	Tapping test, C. 0.25, melter's test showed Slag green	
2:12	Tapped in ladle, aluminum, 2 pounds added in the furnace	
2:17	Pouring in ladle 5 minutes Held in ladle 4 minutes	
2:19	Pouring casting	
	Spoon test for melt supt., quiet, Spoon test for laboratory, quiet	
2:30	Skull on ladle, full bottom	

RADCLYFFE FURNESS: In reply to the comments by W. H. White of the U. S. Naval Gun Factory, Washington, D. C., on my paper, it is evident that I have not made myself clear. I mention that in the silica bottom lies the superiority of the acid process over the basic. Not for one moment do I mean to imply that the "pick-up" of a few points of silicon will make the difference between a good and bad heat. I have endeavored to emphasize the fact that this "pick-up" of silicon will not occur until all of the various phenomena, such as a good slag, a hot bath, etc., have been obtained, and that this "pick-up", or "condition", as I call it, is so well marked as to be easily seen by any one of experience, thus giving the acid melter a decided advantage over the basic.

THE BASIC OPEN HEARTH PRACTICE

By E. A. Whitworth

Abstract

This paper has three divisions, the history of the basic open hearth steel melting practice, furnace design, and practice for high grade carbon forging steel. The production of basic open hearth steel has increased enormously since the early days of the industry. Furnace construction has been improved by devices for lengthening the furnace life, such as water cooled ports, buckheads, valves, etc. The basic open hearth process will permit such varying percentages of pig iron and scrap in the charge that it readily accommodates itself to local conditions without undue increase in costs. The largest part of the basic open hearth tonnage is made in stationary furnaces, the pig iron charge being regulated to give the greatest efficiency. The author gives the method that should be followed in the making of first-class forging steels in order to obtain the best results.

IN presenting a paper on the basic open hearth steel melting practice in the time allotted, it will be impossible to cover the subject in detail, so I have chosen to divide my paper as follows, dealing more or less generally on each point:

1. History
2. Furnace Design
3. Practice for high grade carbon forging steel.

Introductory

The basic open hearth process has been an extremely important factor in the development of our steel industry, having made available the great natural resources of iron ore, giving us a wide range of steels suitable for all commercial uses at a relatively low cost.

The process allows for the production of steels from a great variety of charges, and by the variation in practice, makes pos-

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sible the working of the process economically with regard to the supply of scrap and pig iron.

The development of the process has made possible the use of iron of any phosphorus content, which makes possible the use of ore deposits which could not otherwise be used, and the converting of this high phosphorus iron into low phosphorus steel scrap in the basic open hearth furnace has enabled one to use a cheaper scrap for the acid open hearth process, making possible cheaper production.

History

Before proceeding with the details of the paper, a brief history of the process might be of interest. From 1857 to 1861, William and Frederick Siemens in England developed gasification of the fuel in combination with a new regenerative principle applied to the heating of the gas and air for combustion. From 1863 to 1867 William Siemens and the Martin Brothers of France developed the pig and scrap method successfully and by 1868 William Siemens had developed successfully the pig and ore process. In 1879 the Thomas Gilchrist, or basic process, as applied to the Bessemer converter, was demonstrated as a commercial success at Middlesborough, England, and its application to the Bessemer and open hearth process spread rapidly, particularly on the continent, to make available the large deposits of high phosphorus ores.

Samuel T. Wellman built the first successful open hearth furnace in this country at the Bay State Iron Works of South Boston in 1869. It was five to six ton capacity and melted on an acid bottom. Wellman and George W. Goetz, both of the Otis Steel Company at that time, made steel on a basic bottom at their plant for about four months and discontinued the experiment. The manufacture of the first basic open hearth steel as a commercial product was produced at the Homestead Works of Carnegie, Phipps & Company, March 28, 1888. The plant consisted of four small furnaces, with dolomite and tar bottoms. By the close of 1890 the Homestead Works had sixteen basic open hearth furnaces, varying from fifteen to thirty-five tons. Considerable trouble was had in operations, due mainly to bottom troubles, until improved methods of putting in bottoms with magnesite were put into practice.

It was estimated in 1890 that the production of basic open hearth steel was 90,000 net tons out of a total of all open hearth steel of 575,000 tons. Present day production with full capacity will be about 30,000,000 tons.

Furnace Construction

In the early construction of furnaces the checker chambers were directly under the hearth of the furnace. No attempt was made to direct the flame by means of ports and the roof of the furnace was burned out very rapidly.

The Lash type of furnace with horizontal checkers, using natural gas, was the first successful basic open hearth furnace being operated at Homestead. This furnace has been modified and improved until today it is very efficient, both from the standpoint of production and life, but on account of the scarcity and high price of natural gas and the uncertain supply in the winter months, the natural gas furnace has rapidly been replaced by furnaces using producer gas, oil or coke oven gas.

The producer gas furnace is of entirely different port construction from the natural gas or open port furnace, in that it is necessary to preheat the gas in the gas chamber in order to obtain adequate flame temperature. This makes necessary larger regenerative systems and more complicated and costly furnace construction.

Like natural gas, coke oven gas cannot be preheated without breaking up and has the same advantages over producer gas in the elimination of costly gas-making equipment, making more simple the port, uptake and cinder pocket construction.

Furnace construction for all furnaces is also simpler and less costly than for producer gas, however, producer gas construction up to the port level with knuckle point of roof six inches below the main roof with port roof 12 inches above the knuckle point, having proven to give best oil consumption.

There are many improved devices for preserving and lengthening the furnace life in the form of water cooled ports, buckheads, skewbacks, back and front wall doors and frames, valves, dampers, and reinforced arch roof construction. These cooling devices are warranted only up to the point where the cooling effect begins to lessen the thermal efficiency.

The following is considered well-placed and furnace design practice:

Fuel—producer gas
Capacity—100 tons
Bottom { 24 inches of fire brick
12 inches of mangesite brick
12-18 inches of burned magnesite
90 feet from center to center of furnaces.
Skew back—60 inches above sill-line.
Roof { 12 inches standard and 18 inches rib brick
24 inches spring
Water cooled doors and door frames, front and back wall slay line coolers.
Metal case brick bulkheads.
Air regenerators—For one, a minimum capacity of 70 cubic feet per ton of steel and minimum heating surface of 60 square feet per ton.
Gas regenerators—For one, a minimum of 50 cubic feet of heating surface and 100 square feet heating surface.
Valves—Damper type.
Producers—mechanically fed and operated, two per furnace, capacity to gasify 3,000 pounds of coal per hour per producer.
Stock—150 feet minimum.
Waste Heat Boilers.
Covered stock yard with bin system for raw materials and refractories.

Basic Open Hearth Practice

The basic process permits such varying percentages of pig iron and scrap in the charge that it readily accommodates itself to local conditions without undue increase in costs.

Where scrap is plentiful and cheap it is possible to operate on a 35 or 40 per cent pig iron and 60 to 65 per cent scrap charge. Where pig iron is scarce and high priced, it is possible to charge 100 per cent scrap, using coke to get the necessary carbon in the melting. Other localities may have a plentiful supply of pig iron at a relatively low cost, in which case the duplex process is used, which is the combination of the Bessemer and tilting furnace. Stationary furnaces do not operate to give good practice on charges running over 60 per cent pig iron, because of excessive overflow of slag and comparatively high losses.

The largest part of the basic open hearth tonnage is made in stationary furnaces, the pig iron charge being regulated to give best efficiency. Limestone scrap and pig iron are charged in order for low percentage of pig charge, and limestone, ore, scrap and in two to three hours pig, for high pig charge, either hot or cold, whichever is available. After the hot metal is added a reaction starts with the oxidation of silicon, manganese, phosphorus, iron and carbon to a small extent. The slag formed is

high in iron oxide and silica and is low in lime and magnesia and contains a large portion of the manganese and phosphorus, which is allowed to drain from the furnace. The tapping slag is formed from the limestone as the heat melts. Regardless of the loss of manganese and iron in the run off heats, it makes for faster working on the high pig iron basis. The average basic pig iron calls for silicon averaging 1.00 per cent, manganese 1.50 to 2.00 per cent, sulphur 0.040 per cent or under. Phosphorus as yet has not become troublesome. The manganese content varies quite widely but the high manganese is found quite extensively in use, primarily in the making of high grade steels as alloy and carbon forging steel, in which cases the low pig iron percentage in the charge is used so as to maintain the manganese in the final slag and maintaining a higher residual manganese in the bath itself.

Manganese is a very useful element both in the slag and in the steel. In the first place it confers fluidity in the slag as well as basicity, prevents the absorption of sulphur in the iron and breaks up FeS when formed, acts as a deoxidizer in the later stages of the heat and lessens the amount of non-metallic inclusions.

In the making of first class forging steels, the best results are obtained as follows: For a charge of 210,000 pounds use limestone charge of at least 10 per cent, or 21,000 or 22,000 pounds; 60 per cent clean scrap and as much heavy scrap as is available, and 40 per cent hot metal. With pig iron of 0.90 to 1.00 per cent SiO_2 and 1.75 manganese and fairly sharp working furnace, using oil for fuel, the heat will melt close enough to the desired tapping point in carbon so that it will not be necessary to use an excessive amount of ore for decarburization. There should be no addition of ore for at least 30 minutes to an hour before tapping so as to insure the absence of FeO in the bath. After the bath has been worked down in carbon to the go-ahead point and the slag is shaped up and the temperature is about that which is wanted by the melter, the addition of 2500 pounds of 10 per cent SiO_2 pig is made to the bath after the final preliminary test is sent to the laboratory for analysis, elements determined being carbon, manganese and sulphur. It takes from twenty minutes to half an hour to get results back to the open hearth, during which time the oxidation of the silicon rather than the carbon takes place, allowing the melter to figure the bath the

same as when the final test was sent to the laboratory. The use of ferrosilicon at this point is very beneficial as a deoxidizer because its oxide SiO_2 seeks out the manganese oxide suspended in the metal, forming manganese silicate, which is easily fusible at pouring temperature, causing it to coalesce and go into the slag readily, while the manganese oxide is likely to remain suspended, causing defects in the metal when cold. The silicon also reacts with any carbon monoxide or ferrous oxide dissolved in the bath.

In order to guard against rephosphorization, it is necessary to have a highly basic slag with at least 55 per cent active bases, CaO and MgO. This strong basic slag also favors removal of sulphur.

Before the silicon addition, the melter has the bath in shape from the slag and temperature condition. From this point on the flame in the furnace is reduced, causing the slag to cool decidedly, the temperature of the steel underneath being only slightly reduced on account of the slag being a poor heat conductor. This thermal change has the effect on the slag of increasing its affinity for oxides, principally FeO and MnO.

After the result of the final preliminary analysis is received from the laboratory, and before the bath is allowed to come back to action in the slightest degree, the necessary amount of ferromanganese to meet the chemical specifications is added to the bath, and after waiting from five to seven minutes the heat is tapped into the ladle. When the ladle is about ⅓ full, the silicon necessary to obtain chemical specifications is added, after which ⅔ of a pound of aluminum per ton of steel is added. The ladle is then taken to the pouring platform where the heat is teemed through a 2-inch nozzle into the ingot molds.

The practice which I have just described is used in the melting of alloy steels and high grade carbon forging steels. In most plants, however, it requires skill and good judgment on the part of the men in the shop, and good results can only be obtained to the degree of the training of the organization.

CHAIRMAN J. A. MATHEWS: There is no contributed discussion on this, so the discussion of the two processes, or a comparison of them, or their differences, is now in order. I am sure there is a good deal to be said about it, aside from what has been said this morning by the speakers. It is a large subject. Are there any questions to be asked of the speakers?

H. J. STEGEMAN: What causes laminations in steel? Does it occur after the steel is rolled and fabricated, or is it caused in the melting or casting practice?

CHAIRMAN MATHEWS: Are you referring to carbon or alloy steels, or to a special type of steel?

H. J. STEGEMAN: I refer to carbon and manganese steel. It seldom happens in the chromium steels.

CHAIRMAN MATHEWS: Will the speakers discuss the cause of laminations.

RADCLYFFE FURNESS: I think it would be quite difficult to give all the causes for laminations, because "laminations" is a term that is applied to innumerable defects that occur in steel. The so-called lamination can come from a blow-hole, a small spot of slag, oxides, or any foreign material; they can also come from a slip between crystal faces.

Now, for the reasons that I tried to point out in my paper that acid steel has a better chance of being clean, a better chance of being free from slips than basic steel, I feel that it has a better chance of being free from laminations.

CHAIRMAN MATHEWS: Any other questions?

DR. ZAY JEFFRIES: I would like to take this opportunity of putting some questions to the steel melters in a border line field between heat treatment of solid steel and the behavior of steel when it changes from the liquid to the solid state.

The existence of delta iron is now thoroughly established. That is, when pure iron first solidifies, it crystallizes in what is called the body-centered cubic space lattice. Then, on cooling, to approximately 1400 degrees Cent., the body-centered space lattice is transformed into a face-centered cubic space lattice, which represents a more dense packing of the iron atoms. This transformation takes place with evolution of heat. Ranging from 1400 to 900 degrees Cent., the face-centered cubic lattice, called gamma iron, persists. At 900 degrees Cent. the iron goes back again to the body-centered cubic lattice, with an increase in volume in the neighborhood of 1.4 per cent. The addition of carbon to pure iron raises the temperature of the transformation from delta to gamma iron.

Apparently, according to Dr. V. N. Krivobok, at approximately 0.55 of a per cent of carbon the iron solidifies directly in the gamma condition—that is, in the face-centered condition or more dense packing of the atoms. It would appear, then, that carbon steels containing less than approximately 0.55 per cent carbon should undergo a marked shrinkage in the ingot mold.

It would be expected that the shrinkage would be less with, say, 0.40 per cent carbon, than it would with 0.20 per cent carbon. That is a field in which the melters must have had a great deal of experience. And what I would like to ask is, first, can the melters, from their experience in the teeming of ingots, state definitely that there is such a change in the low carbon steel ingots after solidification, and, secondly, is that change, if it has been observed, absent in steels containing 0.55 per cent carbon or more?

CHAIRMAN MATHEWS: I understand, Dr. Jeffries, you would like those who are familiar with melting practice to state whether there is any observ-

able phenomenon taking place in the translation from delta to gamma iron. Can you answer that, Mr. Furness?

RADCLYFFE FURNESS: I would like to have the question put again. Is it as to whether you noticed a change in volume at a certain stage in the solidification of the ingot?

DR. ZAY JEFFRIES: That is right.

RADCLYFFE FURNESS: Whether there is a change in volume?

DR. ZAY JEFFRIES: A shrinkage, in fact, while the steel is still white hot.

RADCLYFFE FURNESS: And an expansion afterwards.

DR. ZAY JEFFRIES: The expansion is observed very readily; that is, the expansion that accompanies the transformation at the lower critical temperature.

RADCLYFFE FURNESS: I would say yes, that I have seen something similar to the above. My example is crude, but I think positive.

When pouring an ingot of any magnitude, after you have poured well up into the mold, it is my understanding, and I believe the general belief, that the ingot is self-supporting, that the skin has shrunk away from the side of the mold, and the fluid metal is held within the skin. In other words, that the skin is not in contact with the mold. I know of a case where an ingot of very large area, after it had been poured, burst the skin and let the metal down between the skin which had been formed and the mold.

Perhaps I have not expressed myself clearly. The ingot was poured —everything was through—the ladle had gone away, and we suddenly saw some metal come out between the bottom and the mold. Later, in taking the mold off we found that the skin of the ingot had broken, and the metal had come out and run down between the original skin and the mold, and was deposited on the bottom.

Now, whether the case mentioned was due to an undue local expansion of the mold in the neighborhood of the broken ingot skin, I cannot say, but the ingot had stood as finished for fully four minutes before the phenomenon occurred. This is the only case that I know of in my experience which would seem to have any bearing on the question asked.

CHAIRMAN MATHEWS: Are there any other observations on this matter?

IVAN RACHEFF: Dr. Jeffries' question is very difficult to answer due to the fact that the solidification will take place in a number of different conditions and will at the same time depend entirely upon the temperature of the steel, upon the size of the mold, the time of solidification, and the evolution of the gases in the meantime. Those conditions are never the same, irrespective of identically the same chemical analysis.

D. J. GRANGER: I would like to ask something about the S. A. E. 1020 steel. We were making a small part about four inches long that had to be drilled with a 7/16 inch high speed steel drill. We had recently changed from ordinary mild steel to S. A. E. 1020 with the idea that it would machine more readily. There were 10,000 forgings made of this steel and the customer complained about the difficulty he had in drilling the S. A. E. 1020 steel. It broke his drills, and he said it cut his production down about fifty per cent.

We had another case similar to that of S. A. E. 1020 steel on a machine

lever. This lever was drilled and also hollow milled. They used to break their drills also. I was wondering if the S. A. E. 1020, properly made, would do that, and if it does, if it could not be improved in some way by adding either a little sulphur or phosphorus, or something, to make it machine more readily and still not change the strength of the material very much.

CHAIRMAN MATHEWS: You cannot have too much sulphur and phosphorus for then it would not be S. A. E. 1020 steel.

D. J. GRANGER: Well, that is true, but there is open hearth steel that they use and carburize, and it still seems to be strong enough for the purpose. It seems to me that it is a question there of the possibility of probably improving the S. A. E. 1020 steel.

I might also say that in drilling that 7/16 hole, after we got down about three inches, the end of the drill would force its way and drill an irregular hole, forcing the round section to one side. In other words, the hole was not a perfect round. You might say that was probably due to forcing the drill too rapidly, but they have been drilling mild steel under the same conditions. S. A. E. 1020 is supposed to be a standard steel and ought to be a uniform grade of steel.

CHAIRMAN MATHEWS: Are any of the makers of S. A. E. 1020 steel in the room?

MEMBER: I might say that S. A. E. 1020 is one of the most difficult grades of basic open hearth steel that the open hearth melter has to make.

CHAIRMAN MATHEWS: If there is no further discussion, we will have the paper on "Electric Furnace Steel."*

The last paper of this series begins on the next page.

*Presented by Jerome Strauss, U. S. Naval Gun Factory, Washington, D. C.

ELECTRIC FURNACE STEEL

By F. T. Sisco

Abstract

The basic electric process is used for the manufacture of high grade alloy and tool steel ingots, occasionally for castings. The acid process is used principally for castings. The advantages of the electric process are: (1) extreme flexibility and (2) high quality steels produced in tonnage lots. The direct arc furnace with a non-conducting hearth is used almost exclusively in the United States. In the basic electric process the scrap is melted under oxidizing conditions that may be closely controlled. Melting may thus be with complete oxidation, with partial oxidation, or without oxidation. Under average conditions melting with partial oxidation is productive of the highest grade steel. As there are no oxidizing gases present in the electric furnace, iron oxide in the form of iron ore, roll scale or the oxide on the scrap must be used to supply the oxygen. The silicon and most of the manganese are oxidized and removed by the time melting is completed. The oxidation of the silicon is complete and the oxidation of the manganese can be controlled. The removal of the phosphorus depends upon the basicity of the slag, an excess of oxygen and a relatively low temperature. In melting with complete oxidation, practically all of the phosphorus is eliminated; in partial oxidation part of the phosphorus is removed; and in melting without oxidation the phosphorus is unaffected. The oxidation of the carbon is also dependent upon the amount of oxygen present and takes place most rapidly at a high temperature. After the oxidizing slag is removed the metal may be recarburized with ground electrodes or other form of carbon. Recarburization is usually necessary in melting with complete oxidation, but in general is not good practice.

Deoxidation and desulphurization take place in the final period and are accomplished by means of a very basic, fluid slag containing an excess of carbon, calcium carbide or both. Deoxidation takes place first in the slag where ferrous and manganese oxides are reduced to their respective metals. The deoxidation of the molten bath occurs at the plane of contact between metal and slag by migration of dissolved ferrous oxide from metal to

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slag to restore the disturbed equilibrium. Practically all of the ferrous oxide in the metal is thus eliminated. Part of the manganese oxide in the bath is deoxidized. The remainder remains in the metal until it reacts with silica later in the period. The addition of ferro-manganese is made after the slag is deoxidized. Ferro-silicon is added to degasify the metal and remove carbon monoxide. The reaction product, silica, reacts with suspended manganese oxide to form manganese silicate, which is liquid at bath temperature and which coalesces into particles large enough to rise to join the slag. The deoxidizing slag desulphurizes almost completely. Calcium carbide is a more efficient desulphurizing agent than carbon. After deoxidation and desulphurization are complete and all of the alloys added, the temperature is adjusted and the heat tapped. Electric steel is usually poured cold to restrain piping and cracking.

Introduction

THE electric process for the manufacture of steel, although less than 20 years old, has grown from an experimental process producing only 13,672 tons in 1909 to a commercial process producing 432,526 tons in 1924, or an increase of more than 3000 per cent. In the past decade the production of electric steel has increased more than 500 per cent while the total steel production has increased only 18 per cent. This growth has been a healthy one; it has been due to the advantages of electric steel over the product of any other process, advantages that more than overshadowed its disadvantage of higher cost.

The outstanding advantages of the electric process are flexibility and the production of steels of high quality in tonnage lots. It is more flexible than any other process. It can be used to melt cold charges or refine molten metal. It can be used for ingots or castings. It can melt and refine steel or pig iron. The temperature can be controlled closely; and the two impurities, always present in pig iron and steel scrap, sulphur and phosphorus, can be reduced to a commercially irreducible minimum. It is the only commercial process that will both oxidize and deoxidize by means of slags that may be made oxidizing or reducing at will.

With the electric process, steels of crucible quality can be produced in lots up to 30 tons or more at a time. It can refine

a relatively poor grade of pig iron and steel scrap and produce an alloy or tool steel far better than either the Bessemer or open hearth process and at a cost only slightly higher.

General Divisions of Electric Steel Manufacture

Electric furnaces may be lined with either acid or basic refractories. The acid electric process is similar to the acid open hearth process in operating details and chemical reactions and so may be dismissed with only a few words. The steel melted in acid furnaces is confined principally to the plain carbon grades used for castings. No sulphur and phosphorus removal takes place in the acid furnace; the process is almost wholly a melting and superheating operation. Acid electric steel is ordinarily of higher grade than that of other melting processes used in foundry work. This, coupled with the flexibility of the process, has resulted in the electric furnace becoming the preeminent melting medium in the jobbing foundry.

In the basic process the furnace is lined with basic refractories, magnesite brick for the brickwork of the bottom and lower side walls and ground magnesite and dolomite for the sintered bottom and banks. The slags used contain an excess of active base (calcium oxide, CaO). By the proper control of the chemical characteristics of the slag nearly all of the phosphorus and sulphur may be removed from the metal. In addition—and this is a most important function—the slag may be made deoxidizing, thus aiding in the complete elimination of oxides and gas dissolved or suspended in the bath.

There are two main divisions of the basic process: (1) the cold scrap process; and (2) the hot metal process. In the former, scrap is charged into the electric furnace. This is melted and the oxidizable impurities removed either wholly or in part. The oxidizing slag is removed and a new slag formed. The function of this final slag is to deoxidize and desulphurize the metal and thus produce sound steel.

In the hot metal process a charge of partly refined molten metal is poured into the electric furnace where refining is completed. Basic open hearth metal is usually used; hence it is only necessary to deoxidize and desulphurize in the electric furnace. As the basic open hearth is an oxidizing process, all of the oxidizable elements will have been removed before the metal is charged

into the electric furnace. We may say that the hot metal process is a superrefining process. The hot metal process is often known as duplexing and is only practical in the large steel plant where an unlimited supply of hot metal is available.

Costs are much higher in the cold scrap process. This is due to the excessive power consumption in melting. The high power cost of melting the cold charge is partly due to a high demand charge that the electric steel company must pay to have the power available, even though it is used for only a short period at the beginning of the heat. In the hot metal process this excessive melting cost is not present.

Electric Furnaces

Three types of electric furnaces are used in the production of steel: (1) induction; (2) indirect (or independent) arc; and (3) direct arc. The first two are not used to any extent in the United States and but little more abroad. They are, however, used somewhat extensively in melting non-ferrous metals and alloys. The induction furnace is built on the transformer principle —the molten bath forming the secondary side of a step-down transformer. The furnace is a ring-shaped refractory-lined crucible which holds the charge, surrounded by the primary windings of the circuit. The current induced in the bath is of low voltage and correspondingly high amperage. The disadvantages of the furnace are: (1) very high temperatures cannot be attained; (2) melting cold scrap is impracticable, as a small pool of molten metal must be left in the furnace to start melting in the next heat. In the indirect arc furnace the charge is heated by radiation from the arc of two or more electrodes suspended above the charge. This type furnace has the disadvantage that the upper part of the bath may be overheated while that portion near the bottom will be too cold.

The direct arc furnace is of two types: (1) non-conducting hearth; and (2) conducting hearth. The former is used almost exclusively in the United States and is exemplified by the Heroult and the Moore furnaces. The most common conducting hearth furnace is the Greaves-Etchells. Practically all direct arc furnaces are three phase. Non-conducting hearth furnaces have three electrodes let down through the roof at the vertices of an isosceles triangle. Conducting hearth furnaces have two or multiples of

two electrodes connected to two of the phases; the bottom is connected to the third phase. The advantages claimed for the conducting hearth furnaces are: (1) absence of violent power surges in melting; (2) steadier load; and (3) convection currents in the molten metal which aid in refining. The chief objection to the furnace—from the standpoint of the American furnaceman—is liability to bottom trouble.

General Details of the Direct Arc, Non-Conducting Hearth Furnace

Fig. 1, a section through a 6-ton Heroult furnace, shows the details of construction and lining. The latest model furnace dif-

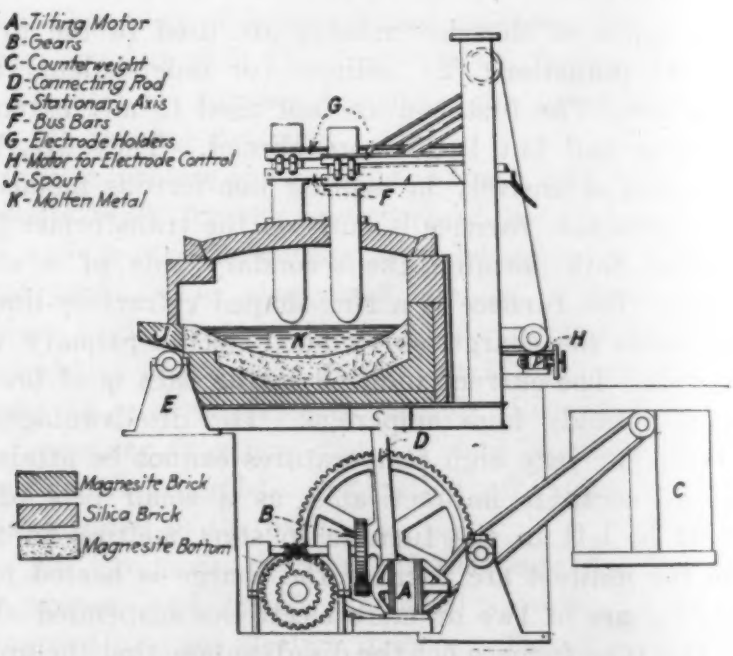

Fig. 1—Section Through a 6-Ton Heroult Electric Melting Furnace.

fers from the one shown in Fig. 1 in having a different tilting mechanism. The newer furnace rests on rockers and is tilted with a motor and without the aid of a counterweight. The electrodes are set somewhat closer in the new type furnace and the arrangement of the electrode masts is improved.

The power for the electric furnace is brought into the plant by high tension feeders. At the furnace it is transformed to a current of about 100 volts. The amperage varies with the size of the furnace; for the 7-ton Heroult it is about 10,000 (maxi-

mum) amperes for each phase. The power factor is usually about 0.90. The electrodes may be graphite or amorphous carbon. The latter are cheaper and stronger than graphite, but must be twice as large for the same current-carrying capacity. Graphite electrodes have higher thermal conductivity than amorphous carbon. With graphite there is less current and heat loss at the threaded joint than with amorphous carbon. Both kinds of electrodes have their advantages and disadvantages; usually the choice is governed by the size of the furnace, the kind of steel made, and often by the personal preference of the furnace operator.

The basic furnace is lined with magnesite brick up to and slightly above the slag line. The upper walls and roof are of silica brick. The bottom proper is made of ground magnesite mixed with a little ground basic slag and occasionally with tar or molasses to make it stick together. This is shoveled into the furnace in thin layers and sintered into a hard vitrified mass. Dolomite is usually used for the repairs to the bottom and banks which are made after each heat. Usually a calcined (burned) dolomite is used. Under average conditions, the roof and lining last for 100 to 150 heats in the cold scrap process and two to three times as long in the hot metal process. With care the bottom lasts indefinitely.

Furnace capacities vary from 1 to 10 tons for the cold scrap process and from 15 to 40 tons for hot metal furnaces. The usual size is 7 tons for the former and 30 tons for the latter. The three-ton furnace is used extensively in the foundry. It is customary to overcharge electric furnaces 10 to 25 per cent.

Charging

As typical of basic electric furnace practice we will describe the process of making a 6- to 8-ton heat of high grade carbon or alloy steel, beginning with the charging of the scrap and ending with the teeming of the ingots.

After the necessary repairs have been made to the bottom and banks 500 to 600 pounds of limestone are charged on the bottom of the furnace. The amount of limestone used varies with the size and relative cleanliness of the scrap and with the melting practice used. The furnaceman charges enough to have 40 to 55 per cent CaO in his slag. With a clean scrap and no ore 300

to 500 pounds of limestone are sufficient; with dirty scrap, or when ore is added to the charge, 600 to 800 pounds are necessary.

If it is desired to carry oxidation to completion in melting, iron oxide in the form of ore or roll scale is next charged into the furnace. The amount of this added also depends wholly upon the character of the scrap and upon the melting practice used. Often the furnace operator will delay the addition of ore until the metal is melted.

In charging the scrap the heavy material is charged first. This is followed by the medium sized scrap. The small sized scrap is charged last. The grade and character of the scrap used in the basic electric process varies widely in different plants. In general it has been found of advantage to use a clean low phosphorus scrap for melting high grade alloy and tool steels. With a high grade, clean scrap it is not necessary to carry oxidation to completion. When the metal is not over-oxidized in melting deoxidation is simpler and a better steel is the result. In the electric process no oxidizing furnace gases are present in the melting period, hence the electric furnace is an efficient melting medium for scrap of small size. Punchings, clippings, flashings, and other small thin sections, even turnings and borings, can be used. This has given the electric process a great economic advantage and has been a large factor in keeping costs to a minimum. Most electric furnaces are charged by hand. Charging a 7-ton heat takes 30 minutes to 1 hour.

Melting

As soon as the furnace is charged the current is turned on. Electrode control is automatic. By means of rheostats we can regulate exactly the amount of current delivered to the electrodes. By means of relays and raising, lowering, and braking contactors the electrode movement, up and down, is controlled so that the arc is of the proper length and intensity to give the temperature desired. This arc length and resulting temperature will be maintained indefinitely until it is desired to change the current input by changing the position of the rheostats.

As soon as the current is turned on the furnace and the arcs strike, the electrodes start boring down through the charge. By the time they reach the bottom there is a pool of molten metal on the bottom of the furnace. The electrode movement is then

upward as the scrap around the sides of the furnace melts and increases the depth of the pool. By the time the scrap is all melted and the bath is sufficiently fluid the limestone and ore on the bottom of the furnace have risen to the top to form the slag. Oxidation is now practically complete.

The Chemistry of Oxidation

During melting the silicon and manganese in the charge are oxidized; the former is wholly eliminated, the latter partially removed. The oxidation of the manganese can be controlled to some extent; the oxidation of the silicon is complete. The reactions are

$$(1)\quad 2\,FeO + Si \rightarrow 2\,Fe + SiO_2$$
$$(2)\quad FeO + Mn \rightarrow Fe + MnO$$
$$(3a)\quad MnO + SiO_2 \rightarrow MnSiO_3$$
$$(3b)\quad FeO + SiO_2 \rightarrow FeSiO_3$$

The manganese and ferrous silicates formed rise to join the slag. By the time the charge is melted reaction (1) is complete. More than half of the manganese is oxidized during melting. The oxidation of the residual manganese becomes increasingly difficult as the percentage becomes lower.

On account of its deoxidizing powers it is of advantage to have 0.15 to 0.35 per cent manganese in the molten bath when oxidation is complete. When the residual manganese is less than 0.10 per cent it is certain that oxidation has been carried too far. It is very difficult to completely deoxidize an over-oxidized metal. Poor steel is likely to result.

The oxidation of the phosphorus depends upon three factors: (1) an excess of available oxygen; (2) a very basic slag; and (3) a comparatively low temperature. The phosphorus is oxidized to phosphoric acid (4a); this combines with ferrous oxide to form phosphate (4b).

$$(4a)\quad 5\,FeO + 2P \rightarrow P_2O_5 + 5\,Fe$$
$$(4b)\quad 3\,FeO + P_2O_5 \rightarrow (FeO)_3.\ (P_2O_5)$$
$$(4c)\quad (FeO)_3.\ (P_2O_5) + 3\,CaO \rightarrow (CaO)_3.\ (P_2O_5) + 3\,FeO$$

The ferrous phosphate formed by reaction (4b) is relatively unstable; consequently when the ferrous phosphate comes into contact with calcium oxide (CaO), a much stronger and more active base, reaction (4c) takes place. The resulting calcium phosphate is stable provided no reducing agents or free silica are present

in the slag. In normal conditions, the slag will be oxidizing, all of the silica will be combined as calcium silicate and sufficient excess calcium oxide will be present to cause reaction (4c) to go to completion.

In normal furnace practice the oxidation of the phosphorus takes place after all of the silicon and most of the manganese are oxidized and before an appreciable amount of the carbon is oxidized.

Below a temperature of about 2550 degrees Fahr. (1400 degrees Cent.) phosphorus is oxidized before the carbon. Above this critical temperature the opposite is true. Hence it is important that the temperature of the metal is relatively low, to insure complete oxidation of the phosphorus. This is nearly always the case in melting cold scrap where the temperature increases gradually.

The carbon is oxidized by reaction (5). This reaction:

$$(5)\ FeO + C \rightarrow CO + Fe$$

is endothermic (absorbs heat) and, as stated above, only takes place rapidly and completely above the critical temperature. Theoretically, all of the silicon, most of the manganese, and practically all of the phosphorus are oxidized before carbon is oxidized at all. Practically, however, the reactions overlap to some extent, and as they are all dependent upon the amount of available oxygen, the temperature and their heat of reaction with oxygen, it is necessary to control conditions closely in order that the reactions may proceed in the order desired.

Control of Oxidation in Melting

There are three variations of melting practice in the basic process: (1) melting with complete oxidation; (2) melting with partial oxidation; and (3) melting without oxidation. In the first method an excess of iron ore or scale is charged. By the time melting is complete the silicon will all be oxidized. The manganese and carbon will both be below 0.10 per cent and the phosphorus less than 0.020 and usually less than 0.015 per cent (see log sheet Table 1). In this practice a large excess of available oxygen is present. As the temperature increases gradually the oxidizing reactions take place in their theoretical order and are all practically completed. The practice has the great advantage of simplicity; little skill is necessary on the part of the

furnace operator. The disadvantages of the practice are: (1) the metal is usually over-oxidized, making deoxidation more difficult; (2) all oxidizable alloys, such as manganese and chromium, are lost. The simplicity of melting with complete oxidation has resulted in it being the favored practice. It has another advantage in that dirty or rusty scrap may be used. Also, the amount of phosphorus in the scrap may be relatively high; up to 0.100 per cent is quickly and almost completely removed.

Melting with partial oxidation is productive of the highest grade steel. This practice calls for unusual skill on the part of the furnaceman. In melting with partial oxidation a clean, selected low phosphorus scrap is necessary. Little or no ore or scale is charged. The temperature is kept as low as possible in melting, that is, it is necessary to avoid melting down too hot. After melting is complete all of the silicon is eliminated; about half of the manganese (and chromium, if present) will be removed, and the phosphorus, if not over 0.040 per cent, will be 0.020 or below (see log sheet, Table II). A variable amount of carbon is oxidized, depending upon the percentage in the charge and the amount of oxide present. The greatest difficulty present in melting with partial oxidation is to remove part of the phosphorus without completely oxidizing the manganese and carbon. This difficulty is overcome by controlling the temperature closely and keeping the slag very basic, so that phosphorus removal will take place before the oxidation of the carbon begins.

The disadvantages of the practice are: (1) a relatively high grade scrap (with a phosphorus content of 0.040 per cent or below) must be used; and (2) a high degree of skill is necessary on the part of the furnaceman. The advantages are: (1) the practice is productive of a high grade steel; and (2) a saving in alloys is effected. When the heat is melted so that at least half of the manganese and carbon in the charge are left in the bath, the metal cannot be over-oxidized, hence deoxidation is simpler, more rapid, and more complete, and the resulting steel is of the best possible quality.

In melting with no oxidation, a clean, high grade scrap is used. No ore or other oxide is used. Lime is charged for the slag. When the charge is melted the slag is deoxidized by means of coke. In this practice the oxidizing period is absent altogether; the process consists simply of melting and deoxidizing.

No phosphorus is removed, hence, the percentage in the scrap must be below the percentage permitted in the finished steel. As most electric steel is required to be low in phosphorus, the application of the process of melting without oxidation is limited to a few occasional heats, using the scrap accumulating in the rolling mills of the electric steel company.

Log sheets of Table I and II give the melting practice on representative heats melted with complete oxidation and partial oxidation. Slag and metal analyses are given, together with the details of the furnace practice. Slag compositions given in these logs are approximate, that is, the presence of fluorides has been ignored. Part of the calcium reported as the oxide (silicate) actually exists in the slag as the fluoride or as a silico-fluoride.

Slagging Off and Recarburization

After the heat is melted and the chemical composition is that desired, the furnace is tilted slightly and the oxidizing slag removed by hand rabbling. If desired, the bare bath may be recarburized by adding some form of carbon. Ground electrodes are usually used. The electrode butts and broken pieces that accumulate are ground to 10-mesh or finer and are weighed into paper bags. These bags, containing 10 pounds each, are shoveled into the furnace and poled beneath the surface of the metal where the carbon is quickly dissolved.

If the heat were melted with complete oxidation, the carbon content at the moment of slagging would be 0.10 per cent or below. If medium or high carbon steels are made it is always necessary to recarburize after slagging off. In complete oxidation the bath is practically saturated with dissolved ferrous oxide. The carbon reacts with this dissolved oxide, producing an evolution of carbon monoxide gas (reaction 6), which causes the metal to boil

$$(6) \quad FeO + C \rightarrow CO + Fe$$

violently. Recarburization after slagging has the advantage of ridding the bath of most of the dissolved ferrous oxide but introduces carbon monoxide gas in its place, some of which will be dissolved or entrapped by the molten metal. Another disadvantage is that recarburization with ground electrodes, coke, coal, or the like, introduces solid impurities, as ash, in the re-

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Table I

Log Sheet 1—Log of an Electric Heat Melted with Complete Oxidation

Furnace E
Heat 4,065

Analysis Ordered — C .65/.75 — Mn .30/.50 — Si .15/.25 — S .025 or less — P .025 or less

Time	Log	Additions Pounds	Metal Analysis C	Mn	Si	S	P	Slag Analysis SiO_2	FeO	Al_2O_3	MnO	CaO	MgO	CaS	P_2O_5	P	CaC_2	C
1:25 a. m.	Previous Heat Tapped.....	.....	...	..	...	...	...	....	....	...	...	....	....	....	...	...	...	..
1:35 a. m.	Bottom Repaired—Dolomite..	200	...	..	...	...	...	....	....	...	...	....	....	....	...	...	...	..
1:40 a. m.	Began Charging—Limestone..	650	...	..	...	...	...	....	....	...	...	....	....	....	...	...	...	..
	Iron Ore...	45	...	..	...	...	...	....	....	...	...	....	....	....	...	...	...	..
	Scrap—Mixed Scrap	8,700	*	..	...	.050	.080	....	....	...	...	....	....	....	...	...	...	..
	Rail Ends and Plate..	3,000	*	..	...	.040	.040	....	....	...	...	....	....	....	...	...	...	..
	Punchings & Turnings	4,700	*.20	.50	...	.050	.060	....	....	...	...	....	....	....	...	...	...	..
2:20 a. m.	All Charged—Power on	16,400	*	..	...	.050	.065	....	....	...	...	....	....	....	...	...	...	..
5:05 a. m.	All Melted—First Test Taken.	.....	.08	.05	.005	.042	.013	18.17	15.47	2.73	9.10	41.37	10.21	0.217	2.84	...	...	..
5:20 a. m.	Slag Off — Recarburized Electrodes	150	...	..	...	...	...	....	....	...	...	....	....	....	...	...	...	..
	Bath Wild—Added Ferro-silicon	20	...	..	...	...	...	....	....	...	...	....	....	....	...	...	...	..
5:25 a. m.	White Slag on—Lime	450	...	..	...	...	...	....	....	...	...	....	....	....	...	...	...	..
	Coke (100) Spar (100)....	200	...	..	...	...	...	....	....	...	...	....	....	....	...	...	...	..
5:40 a. m.	Slag Light Brown—Coke (50) Spar (50)	100	†.57	.06	.010	.038	.016	15.23	2.95	3.07	1.25	59.61	11.31	0.850	...	.008	nil	.37
5:55 a. m.	Slag White—Slag Hot	.....	.58	.06	.011	.030	.016	16.17	0.75	2.86	0.21	60.32	11.16	2.01	...	Tr.	nil	.05
6:05 a. m.	Slag Partly Carbide — Added Lime	50	...	..	...	...	...	....	....	...	...	....	....	....	...	...	...	..
	Added Ferro-manganese (80%)	60	...	..	...	...	...	....	....	...	...	....	....	....	...	...	...	..
6:20 a. m.	Slag Strongly Carbide—Very Hot	.....	.62	.36	.017	.018	.018	17.03	0.17	3.43	Tr.	59.73	10.43	2.93	...	nil	1.13	.46
6:25 a. m.	Added Lime (50) Coke (25) Spar (25)	100	...	..	...	...	...	....	....	...	...	....	....	....	...	...	...	..
6:30 a. m.	Heat Hot—Power Reduced...	.....	...	..	...	...	...	....	....	...	...	....	....	....	...	...	...	..
6:35 a. m.	Added Ferro-manganese (80%)	10	...	..	...	...	...	....	....	...	...	....	....	....	...	...	...	..
	Added Ferro-silicon (50%)..	60	...	..	...	...	...	....	....	...	...	....	....	....	...	...	...	..
6:45 a. m.	Slag O. K.—Metal Quiet and Hot	.....	.65	.40	.117	.015	.019	18.43	0.19	3.31	0.06	57.43	10.63	3.01	...	nil	1.40	.31
6:50 a. m.	Added Ferro-silicon (50%)..	15	...	..	...	...	...	....	....	...	...	....	....	....	...	...	...	..
6:55 a. m.	Slag and Metal O. K.—Ready to Tap	.....	.67	.41	.168	.012	.020	18.33	0.20	3.07	0.05	59.43	10.52	3.31	...	nil	1.20	.27
7:10 a. m.	Ladle (Final) Test	.....	.69	.40	.170	.012	.019	18.71	0.14	3.11	Tr.	58.39	10.63	3.40	...	nil	1.06	.31

*Analysis of Scrap and Charge Approximate
†Slag and metal tests taken just before additions were made.

carburizer. This may be a serious factor if 75 to 125 pounds of recarburizer are necessary.

It has been found that the best steel results from melting with partial oxidation, omitting altogether the recarburization with some form of carbon. Then, if it is necessary to increase the carbon content later in the heat, pig iron or washed metal can be conveniently used to raise the percentage the few points necessary to have the carbon within the required limits (see log sheet, Table II).

To curb the wildness resulting from recarburization after complete deoxidation, a few shovelfuls of crushed ferrosilicon are scattered over the surface of the metal. The reaction:

$$(7)\quad 2\,CO + Si \rightarrow SiO_2 + 2C$$

stops the boiling immediately.

Some furnacemen add a portion of the ferromanganese to the metal after recarburizing. A part of the manganese will be oxidized to manganese oxide. When the final slag is added to the metal this oxide must be completely reduced to the metal again before deoxidation is complete, thus increasing the work necessary by the deoxidizing slag. It is better to use ferrosilicon after recarburizing if it is necessary to curb the wildness of the metal. The silica (SiO_2) formed by reaction (7) is contained permanently in the slag and does not appreciably affect its deoxidizing powers. The ferromanganese may then be added later in the deoxidizing period after the slag is free from iron and manganese oxide.

The Deoxidation Period

In the final period in basic electric furnace practice the metal is deoxidized and desulphurized. Deoxidation is accomplished in two ways: (1) by means of a very basic slag containing an excess of carbon, calcium carbide, or both; and (2) by deoxidizing alloys, such as ferromanganese and ferrosilicon. Most of the deoxidation is due to the reducing character of the slag. This reducing slag is unique in ferro-metallurgical processes; in no other steel-making operation can an excess of reducing agents be maintained in the slag. The high quality of electric steel is due principally to the fact that the steel is deoxidized in the furnace; time is thus available for the reactions to become com-

pleted and for the steel to free itself of the non-metallic reaction-products.

In the Bessemer, basic open hearth and acid open hearth processes conditions in the furnace are more or less oxidizing right up to the moment of tapping. The slag ordinarily contains free ferrous oxide and the furnace gases usually contain an excess of oxygen. Thus it is necessary to add the ferro-alloys to the ladle while the heat is tapping, or to the furnace just before tapping. The time between the alloy additions and the teeming of the ingots is often not sufficient for the non-metallic reaction-products to leave the steel completely. In the basic electric process ferro-alloys may be added a half hour or more before the tapping. The alloys become thoroughly distributed and all reactions have time enough for their completion. In addition, the slag accomplishes most of the deoxidizing. Very little is required of the ferro-alloy additions. It is thus readily apparent that the reducing slag of the basic electric furnace practice is responsible for the superiority of basic electric steel.

The deoxidizing period varies from 1 to 3 hours in length. If the metal is melted with complete oxidation, deoxidation is more difficult; it is necessary to hold the bath longer under the deoxidizing slag to insure that the metal will be entirely free of dissolved ferrous oxide.

In basic practice the ferromanganese is added as soon as the slag is white. Ferrochromium may be added at about the same time. The addition of ferrosilicon is deferred until 15 to 30 minutes before tapping. This alloy accomplishes the degasification and final deoxidation and so should not be added until reducing conditions in the furnace have been maintained for one to two hours. The time of adding the various ferro-alloys is illustrated in log sheets, Tables I and II.

The Deoxidizing Slag

The deoxidizing slag is composed of lime, powdered coke, and fluorspar. The amount of the three materials varies greatly, depending upon the furnace practice—that is, whether it is desirable to make the slag weakly or strongly reducing. The white slag is made up of about 12 parts of lime, 2 parts of coke, and 2 to 4 parts of fluorspar. This slag when cooled in air is pure white in color and disintegrates spontaneously and rapidly to a

Table II

Log Sheet 2—Log of an Electric Heat Melted with Partial Oxidation

Furnace C
Heat 3,127

Analysis

Time	Log	Additions Pounds	Metal Analysis C	Mn	Si	S	P	Cr	V
4:30 p. m.	Previous Heat Tapped	.....	...	..	...	...	...	..	..
4:40 p. m.	Bottom Repaired—Dolomite	100	...	..	...	...	...	..	..
	Magnesite	50	...	..	...	...	...	..	..
4:50 p. m.	Belgan Charging —Limestone	500	...	..	...	...	...	..	..
	Scrap—Low Phos..	9,800	*.25	.40	...	.040	.035	..	..
	Crops, High C..	4,500	*.90	.35	.20	.025	.025	..	..
	Small Scrap ...	1,800	*.25	..	...	.035	.040	..	..
5:35 p. m.	All Charged—Power on	16,100	*.45	.40	.10	.035	.035	..	..
8:05 p. m.	All Melted—Test Taken—Slag Thick	.....	.23	.25	.005	.032	.019	..	..
8:20 p. m.	Slag off—Added Spar to Slag....	35	...	..	...	...	...	..	..
8:25 p. m.	White Slag on—Lime	500	...	..	...	...	...	..	..
	Coke (100) Spar (150)	250	...	..	...	...	...	..	..
8:35 p. m.	Slag Brown—Coke (60) Spar (30).	90	†.23	.22	.008	.031	.020	..	..
8:45 p. m.	Slag almost White —Coke	30	.24	.24	.008	.029	.020	..	..
8:55 p. m.	Slag partly Carbide —Fluid	.....	...	..	...	...	...	..	..
	Added Ferro-manganese (80%)..	70	...	..	...	...	...	..	..
9:05 p. m.	Slag Carbide—Hot and Fluid	.....	.27	.60	.019	024	.022	..	..
	Added Ferro-chromium (6% C, 68% Cr)	235	...	..	...	...	...	..	..
9:15 p. m.	Heat—Hot—Power Reduced—Coke..	25	.37	.59	.017	.023	.025	.07	..
9:25 p. m.	Added Ferro-manganese (80%)...	20	...	..	...	...	...	..	..
9:30 p. m.	Slag O. K.—Added Ferro-silicon ...	70	.38	.67	.020	.019	.025	.99	..
	Added Washed Metal—(4% C)....	200	...	..	...	...	...	..	..
9:45 p. m.	Slag O. K.—Metal O. K.—Lime (25) Spar (25).	50	.44	.66	.148	.017	.026	.98	..
9.50 p. m.	Added Ferro-silicon (50%)	15	...	..	...	...	...	..	..
10:00 p. m.	Ready to Tap—Ferro-vanadium (38%)	90	.45	.66	.193	.015	.026	.96	..
10:10 p. m.	Ladle Test	.....	.47	.66	.190	.015	.028	.95	.17

*Analysis of Scrap and Charge Approximate
†Slag and metal tests taken just before additions were made.

Table II (continued)

Log Sheet 2—Log of an Electric Heat Melted with Partial Oxidation

C	Mn	Si	S	P	Cr	V
.45 / .55	.50 / .80	.15 / .25	.030 or less	.030 or less	.80 / 1.10	.15 or more

Slag Analysis

SiO_2	FeO	Al_2O_3	MnO	CaO	MgO	CaS	P_2O_5	Cr_2O_3	CaC_2	C
....	....	...	...	....	....	...	..	..	..	..
....	....	...	...	....	....	...	..	..	..	..
....	....	...	...	....	....	...	..	..	..	..
....	....	...	...	....	....	...	..	..	..	..
....	....	...	...	....	....	...	..	..	..	..
....	....	...	...	....	....	...	..	..	..	..
....	....	...	...	....	....	...	..	..	..	..
17.32	10.37	3.13	5.43	50.21	12.31	.107	.93	..	..	..
....	....	...	...	....	....	...	..	..	..	..
....	....	...	...	....	....	...	..	..	..	..
....	....	...	...	....	....	...	..	..	..	..
14.25	1.87	3.18	.87	61.31	13.65	.34	..	..	nil	.09
15.07	1.03	2.94	.43	60.86	13.43	1.26	..	..	nil	.21
....	....	...	...	....	....	...	..	..	..	..
....	....	...	...	....	....	...	..	..	..	..
15.47	.36	3.26	.39	61.17	12.93	1.67	..	..	.43	.37
....	....	...	...	....	....	...	..	..	..	..
....	....	...	...	....	....	...	.27	..	..	..
....	....	...	...	....	....	...	..	..	..	..
16.39	.21	3.08	Tr.	60.77	13.19	2.06	..	Tr.	.87	.31
....	....	...	...	....	....	...	..	..	..	..
....	....	...	...	....	....	...	..	..	..	..
....	....	...	...	....	....	...	..	..	..	..
16.96	.33	3.17	.06	59.78	13.41	2.37	..	nil	93	.26
17.47	.17	3.26	Tr.	60.13	13.24	2.42	..	Tr.	.74	.17

fine white powder. When the slag is first added to the metal in the furnace, most of the coke burns to carbon monoxide. The rest reacts with ferrous and manganese oxides in the slag or floating on the surface of the metal. When these reactions are complete the coke is practically all gone, hence the slag at once loses its deoxidizing powers. The only advantage of the white slag containing little or no carbon is that there is practically no carbon absorbed from the slag by the metal, hence it is used principally for low carbon steels. In addition to accomplishing practically no deoxidation, it is not efficient in desulphurization.

The carbide slag is made up of 6 parts of lime, 2 to 3 parts of coke, and 1 to 2 parts of fluorspar. Part of the coke burns to CO, part is consumed in deoxidizing the oxides floating on the metal or in the slag itself. The excess lies suspended in the slag. In the vicinity of the arc this coke reacts with lime to form calcium carbide, CaC_2, a reducing agent of great potency. The calcium carbide formed diffuses through the slag until it becomes uniformly distributed. Cooled in the air the slag disintegrates spontaneously, but not rapidly, to a gray powder. When moistened, the characteristic odor of acetylene, from the reaction between the calcium carbide and water, becomes readily apparent.

The carbide slag is an efficient deoxidizing and desulphurizing medium. After 1½ to 2½ hours under this slag the metal is practically free from dissolved ferrous oxide and the sulphur has been eliminated to an irreducible minimum of 0.010 to 0.015 per cent. The only disadvantage of the carbide slag is that carbon is absorbed from the slag by the metal, although with standardized furnace practice this absorption becomes constant and can be allowed for.

Keeping the Slag in Condition

The carbon or calcium carbide in the deoxidizing slag will soon be reduced to zero unless precautions are taken to keep it strongly reducing. Sufficient air leaks into the furnace to react with the carbon or carbide and completely destroy it in less than an hour. There are several other factors that influence the reducing power of the slag. If a section of the bottom refractories works loose and comes up the slag will quickly change in character. The magnesite or dolomite in the bottom contains

up to 6 per cent or more iron oxide which will quickly react with carbon or calcium carbide in the slag. The high magnesia refractory makes the slag thick, a condition which is a factor in preventing carbide formation. A low slag temperature will prevent carbide formation and distribution throughout the body of the slag.

Hence, after the slag has been added to the metal and heated to the proper point the melter keeps it in shape by making additions of lime, coke, or fluorspar, either alone or mixed, as conditions warrant. He will add lime to thicken the slag, or fluorspar to thin it. If the slag becomes watery and mirror-like he will add lime and coke. A shovelful of coke or two is scattered over the slag each time it is necessary to open a door. This will take care of the atmospheric oxygen drawn into the furnace.

If the slag turns a greenish color after the manganese addition, coke is added to reduce the manganese oxide to the metal. The same procedure is used after an addition of ferro-chromium or any other easily oxidizable alloy.

The amount of carbon in the slag is governed by the composition of the steel made, by the amount of oxidation in melting and by the preference of the furnaceman. In general, the slag will contain about 1 per cent calcium carbide and 0.25 to 0.50 per cent uncombined carbon. This percentage gives the slag a characteristic appearance as it lies on the metal in the furnace. In the vicinity of the arc it will be thin and smooth. The rest of the slag, where it is not heated directly by the arc, will be fluffy and will foam slightly. In appearance it may be compared to thick soapsuds. This slag is very efficient in deoxidation and desulphurization.

If high carbon steels are made, and if the melter is exceptionally skillful, he may have 3 per cent calcium carbide in the slag. With this percentage, however, the absorption by the metal may be as much as 8 to 10 points of carbon (0.08 to 0.010 per cent). With such a high percentage of carbide it is sometimes difficult to control exactly the chemical composition.

Deoxidation of the Slag

After the slag has been added to the metal and heated to the proper temperature the first deoxidation is in the slag. The car-

bon or calcium carbide reacts with ferrous or manganese oxide according to the reactions:

$$(8)\quad \left\{\begin{matrix}FeO\\MnO\end{matrix}\right\} + C \rightarrow \left\{\begin{matrix}Fe\\Mn\end{matrix}\right\} + CO$$

$$(9)\quad 3\left\{\begin{matrix}FeO\\MnO\end{matrix}\right\} + CaC_2 \rightarrow 3\left\{\begin{matrix}Fe\\Mn\end{matrix}\right\} + CaO + 2CO$$

These reactions take place in the slag and at the plane of contact between slag and metal.

As deoxidation proceeds the slag changes in color (of a sample, cooled in air) from brown or greenish brown to light brown and, finally, to pure white. Then if more coke is added and calcium carbide formed, the color becomes light gray and then dark gray. When the slag contains carbide the amounts of iron and manganese oxides are generally less than 1 per cent (see log sheets, Tables I and II).

The reduction of the manganese oxide to manganese is always more complete than the reduction of ferrous oxide to iron. This is evident from the analysis given in the log sheets.

Deoxidation of the Metal

After the oxidizing slag has been removed the molten bath contains a variable amount of dissolved and suspended ferrous and manganese oxide. The amount depends upon how far oxidation was carried in melting and whether or not the metal was recarburized. In any case there will be much more ferrous oxide than manganese oxide. After the deoxidation of the slag is complete the deoxidation and elimination of the ferrous oxide dissolved in the metal begin. This deoxidation takes place at the plane of contact between metal and slag. The ferrous oxide in the metal at the plane of contact is soon deoxidized. As soon as this surface layer is free from FeO the equilibrium between liquid FeO and liquid Fe is disturbed and migration of the FeO into this oxide-free layer begins. As fast as the FeO reaches the surface it is reduced by the carbon or calcium carbide in the slag. This deoxidation by the slag continues until the metal is free from all but minute traces of dissolved FeO.

The removal of suspended (dissolved?) manganese oxide is slower and more uncertain. However, there never is as much manganese oxide as ferrous oxide in the metal. During the deoxidation of the metal it is essential that an excess of carbon or

calcium carbide be maintained in the slag during the whole period.

Desulphurization

Desulphurization takes place according to the reaction:

$$(10) \quad MnS + CaO + C \rightarrow Mn + CaS + CO$$

$$(11) \quad 3MnS + 2CaO + CaC_2 \rightarrow 3Mn + 3CaS + 2CO$$

Although some sulphur removal will take place according to the first reaction, calcium carbide is much more efficient in desulphurization. There are five factors that affect desulphurization: (1) carbon or calcium carbide must be present, (2) the slag must be very basic, (3) the slag must be fluid, (4) the slag must be hot and (5) the percentage of sulphur in the slag-making materials must be low.

Probably, if all of the other requirements were fully met, the slag would desulphurize, to a slight extent at least, even though no carbon or calcium carbide were present. This is shown by the fact that a white slag will reduce the sulphur content from 0.040 to about 0.020 per cent in 2 to 3 hours. In the case of a slag containing about 1 per cent calcium carbide a sulphur content of as much as 0.100 per cent will be reduced to .020 per cent or below in an hour or less.

In general, the average electric furnace deoxidizing slag meets all five requirements. The slag is very basic, due to about 60 per cent calcium as calcium oxide. It can be made very fluid by means of fluorspar and can be kept very hot.

It is essential that the sulphur in the lime, coke and spar is low. Apparently the average slag is saturated with calcium sulphide at about 4 per cent, although this saturation point may be increased by increasing the basicity, fluidity and temperature.

Degasification

Calcium carbide, although a very efficient deoxidizing agent is not effective in promoting degasification. Even after the metal is held under a carbide slag for 2 hours, a small test ingot will spark in pouring and will rise up in the mold, due to the evolution of gas in cooling. It is necessary to add ferrosilicon to completely degasify the metal. This is accomplished by the reaction:

$$(12) \quad 2CO + Si \rightarrow SiO_2 + 2C$$

Within a few minutes after adding the ferrosilicon the metal pours quietly and the test piece contracts slightly in solidifying.

The degasification reaction results in the formation of silica, SiO_2, which is probably solid at bath temperature and dispersed throughout the metal in a finely divided state. Deoxidation by calcium carbide has not eliminated all of the manganese oxide suspended (dissolved?) in the metal. The affinity of manganese oxide for silica is high, consequently the following reaction takes place:

$$(13)\quad MnO + SiO_2 \rightarrow MnSiO_3$$

Both MnO and SiO_2 are probably solid at bath temperature but their reaction product $MnSiO_3$ is liquid, and has the property of coalescing and coagulating in droplets of sufficient size to respond to their lighter specific gravity and rise to join the slag.

Summary of Deoxidation

After a heat of electric steel is melted, the metal will contain dissolved ferrous oxide, and suspended (or dissolved) manganese oxide resulting from the oxidation reactions in melting. If the heat were recarburized it would contain carbon monoxide gas either occluded or dissolved. The ferrous oxide and a part of the manganese oxide are eliminated by reaction with the carbon or calcium carbide in the slag; the reactions taking place at the plane of contact between slag and metal.

Carbon monoxide gas is eliminated by the addition of ferrosilicon which reacts with CO to form silica. The silica and manganese oxide suspended in the bath react to form manganese silicate which is liquid at steel-making temperatures and which coalesces and rises to join the slag.

The manganese sulphide in the charge reacts with calcium oxide and carbon or calcium carbide to form calcium sulphide which is soluble and stable in a basic, fluid slag.

These reactions are the principal ones occurring in the deoxidation period. Obviously the amount of the various oxides and silicates in the molten bath depends upon the degree of oxidation of the metal in melting. If the charge were melted with complete oxidation, using an excess of iron ore, the bath would be practically saturated with ferrous oxide. Most of this would be

removed by the recarburizing reactions and practically all of the remainder by the carbide slag.

It has been found, however, that when the charge was over-oxidized in melting it is very difficult to remove all of the dissolved ferrous oxide even by a strongly carbide slag and relatively inferior steel is the result. By restricting oxidation it has been found that deoxidation becomes easier and more complete and a high grade steel is the result.

Finishing the Heat

As soon as the final slag is thoroughly deoxidized alloy additions may be made. As has been stated, ferromanganese may be added as soon as the slag is white, ferrochromium is usually added about the same time. Nickel, copper or molybdenum may be added at any time. Nickel and copper will not oxidize at all, so may be added as soon after slagging off as desired. Molybdenum will oxidize but its oxide is very unstable. Tungsten is usually added after the slag is white. As the melting point of ferrotungsten is higher than steel the bath should be very hot so the alloy will melt to become uniformly distributed.

Ferrovanadium is added just before the heat is tapped; after the ferrosilicon addition. Vanadium is an efficient degasifier, so cannot be added until the metal is free from carbon monoxide.

After the additions are all made and the chemical composition is that desired, the temperature is adjusted and the heat tapped. During the deoxidation period the metal is kept somewhat hotter than is desirable for tapping. The average tapping temperature for high grade alloy and tool steels varies between 2800 and 2900 degrees Fahr. (1540 and 1600 degrees Cent.). The temperature during the deoxidation period will be 3000 to 3100 degrees Fahr. Deoxidizing reactions are speeded up and completed more rapidly if the bath and slag are hot. In addition a high temperature of the metal and slag favors rapid desulphurization.

It is advisable to shut the power off 10 or 15 minutes before tapping and let the metal lie quietly in the furnace while the temperature drops 100 to 200 degrees Fahr. This period of quiet or dead melting is of benefit in that it permits a final cleansing of the metal; last traces of non-metallic inclusions rise to join the slag. After tapping the metal may again be held for a few minutes in the ladle before teeming the ingots.

Electric Steel Pouring Practice

Correct pouring practice is very essential in the production of high grade steel ingots. Steel that is inherently bad cannot be made better by the best pouring practice, but on the other hand a ladle of high grade, thoroughly deoxidized metal can be wholly spoiled by bad pouring practice.

It is almost standard practice to pour cold. The temperature of the metal when the ingots are teemed is intimately connected with the final quality. Cold pouring favors rapid solidification of the metal in the mold, thus preventing cracking. This is the principal advantage. Cold pouring tends to shorten the pipe in the ingot. The metal in the mold is comparatively cold; the metal in the ladle which is being delivered to the mold is considerably hotter. Consequently, the pipe is filled as fast as formed. This advantage is, of course, greater when sink heads are used. It is also believed that cold pouring reduces ingotism.

The principal disadvantage of cold pouring is that it often results in an ingot with a bad surface. In all top pouring there is some splashing; a small amount of metal striking the cold wall of the mold will freeze instantly. If the added metal is not hot enough to melt this bead we have a scab or cold shut on the ingot.

Most electric steel ingots are top poured. Some shops, however, bottom pour. Both methods have their advantages and disadvantages. Bottom pouring produces an ingot having a good surface free from scabs and cold shuts. It permits a number of ingots to be poured at once and at the same temperature. It has the disadvantage of being more costly and difficult to handle successfully. Its principal disadvantage is that the hot metal is fed from the bottom, consequently the maximum amount of main pipe will be the result. Also on bottom pouring, secondary pipes well down in the body of the ingot are often encountered, resulting in the entire ingot being scrapped.

Top pouring has the advantage of producing a sound ingot with the pipe well up in the top. There is little chance of secondary pipe forming. The only disadvantage is the bad surface of the ingot. This is often overcome by the use of octagon or fluted ingot molds and by the use of the proper slurry on the mold wall. Taking all factors into consideration, top pouring is probably the best.

Written Discussion:—By Charles McKnight, Jr., The International Nickel Company, N. Y. C.

From the very beginning of the use of electric furnace for steel manufacture we have heard of its deoxidizing powers, its ability to maintain reducing condition from first to last, if desired, and have learned to think that the more reducing the condition the better the product. Is this always true?

Also, deoxidation has been so emphasized that it has completely overshadowed degasification or, what is more likely, the two are confused. It is asserted by some authorities that, while steel in the open hearth process picks up from the flame sweeping over the bath such gases as hydrogen, nitrogen and carbon monoxide, the bath in the electric furnace is so protected that it becomes very improbable that these gases will be dissolved by the metal. Again, is this true? It is conceivable and sometimes occurs that a bath will be completely deoxidized and yet carry in solution a volume of gases several times that of the steel itself, these gases being principally nitrogen and hydrogen, the former inert, the latter reducing in character and thus conforming in chemical character to the prevailing conditions at the end of an electric furnace heat.

We speak vaguely of degasification and of performing this operation by the addition of silicon, manganese, aluminum, etc., to the bath. Yet the mechanism of degasification is shrouded in mystery and no satisfactory explanation is forthcoming.

That it is possible to have a bath doubly deoxidized—by means of a reducing slag and a silicon content—and yet full of dissolved, occluded, or adsorbed gases was shown in making a series of over a hundred heats of steel high in silicon. The first resulted in a good product, but, soon after the high-silicon crop-ends and mill scrap began to be returned for remelting, trouble was experienced with the steel rising in the mold. In spite of the fact that the practice was as nearly perfect as we could make it, that the charge was high in silicon and that a deoxidizing slag was used from the start, ending with a heavy carbide slag, there would be a remarkable evolution of gas from the ingot just prior to solidification, a "cauliflower" would build up on the hot top and the metal would be full of blowholes. Eventually despairing of obtaining a reliable steel in this manner, we went to the opposite extreme and brought the bath down under an extremely oxidizing slag. The rising in the mold stopped with that heat and has never reappeared, though we have modified our practice so that the oxidizing slag is raked off when the bath is in violent ebullition and the usual white slag built up, from under which the steel is tapped. An interesting feature is that, after the preliminary oxidation, or degasification period, during which it is essential that the silicon be brought down to 0.05 per cent or less, the heat will work thereafter in a perfectly normal way. As soon as the white slag is built, silicon, manganese, or other alloys may be added just as in the ordinary heat, although for these high silicon steels—silicon over 1.00 per cent—we prefer to add most of it about half an hour to an hour before tapping.

Rather wide inquiry resulted in finding that similar troubles had been experienced by others, particularly in making steels from scrap high in silicon and, to a much less degree, with steels high in manganese, chromium, etc. Inquiry also showed that, as far as could be ascertained, this trouble only occurred when the furnace conditions were reducing in character and disappeared when the procedure was changed; also that in open hearth practice similar phenomenon had not been observed.

In evolving an explanatory hypothesis, it was evident that residual silicon in some way affected the volume of dissolved gases and tended to keep them in solution. It seemed reasonable to assume that these gases must be hydrogen or nitrogen or both, since under the reducing conditions and in the presence of so much silicon, oxygen and carbon monoxide must both be practically absent. Writing side by side the fundamental reactions with their corresponding equations for concentrations in homogenous solutions, we have:

(1) $2H + FeO \leftrightarrows H_2O + Fe$ (2) $\uparrow C_H^2 \times C_{FeO} \downarrow = (C_{H_2O} \times C_{Fe})$[1]

(3) $Si + 2FeO \leftrightarrows 2Fe + SiO_2$ (4) $\uparrow C_{Si} \times C^2_{FeO} \downarrow = (C^2_{Fe} \times C_{SiO_2})$

(5) $2CO + Si \leftrightarrows 2C + SiO_2$ (6) $\uparrow C^2_{CO} \times C_{Si} \downarrow = (C^2_C \times C_{SiO_2})$

(7) $C + FeO \leftrightarrows Fe + CO$ (8) $\uparrow C_C \times C_{FeO} \downarrow = (C_{Fe} \times C_{(CO)})$

The right-hand side of the concentration equations can be for all practical purposes, replaced by K in all but (8) and considered constant, so that the arrows show the respective and inter-related changes. For example, in (6) if the concentration of silicon increases the concentration of CO diminishes, as is well known.

Thus, as the residual silicon in the bath becomes higher, the amount of FeO decreases and as the FeO decreases the bath is rendered more capable of holding the hydrogen in solution (equations 1, 2, 3 and 4). On the other hand, the lower the residual silicon the higher the FeO, which tends to drive the hydrogen out of the metal at the same time the carbon is reacting with FeO to form CO, which also escapes in bubbles.

During the melt-down, water vapor from the charge and the air, which it is impossible to exclude entirely, is dissociated under the heat of the arc and the hydrogen, in conjunction with nitrogen, taken up by the melting, or molten metal. The oxygen combines with some of the metal to form metallic oxides, remaining either in the bath or migrating to the slag. As

[1]These equations, true for concentrations of gases, are only roughly indicative for liquid solutions.

long as there is, to a practical extent, any residual silicon in the bath, the amount of FeO is lowered and the capability for retaining hydrogen is increased, but as soon as the silicon is sufficiently low the bath oxidizes freely, with the formation and ebullition of CO. The conditions tending to hold hydrogen in solution are then reversed and the hydrogen and water vapor resulting from reaction (1) leave the bath by ebullition. It may be that nitrogen is also reduced in volume at this time, as there would be a tendency to establish equilibrium of concentration between the nitrogen content of the steel and that of the gas bubble as it passes up through the metal.

The apparently paradoxical behavior of silicon may be observed. In the first, or oxidizing, period it tends to keep gases in the steel and yet in the final deoxidizing period it is intentionally added as an efficient degasifier. As a matter of fact, the action in both cases is the same. Silicon —or any other degasifier—apparently works through some property of making the solvent power of the metal great enough to hold gases. If the action were to drive out the gases we would expect on the addition of silicon to see them bubbling from the steel. No such action occurs, though the quieting effect is obvious, so it must be that the steel, through the silicon, has acquired a greater solubility for the gases which, up to a certain critical concentration, remain dissolved or occluded or adsorbed, as you please, through the solidification phase.

Whether or not such a hypothesis conforms with the facts, it has, nevertheless, been demonstrated that under certain conditions a period of oxidation tends to free the bath from gases, other than oxygen, and has distinctly beneficial results. In fact, it might be considered that the method of partial oxidation is preferable to either of the other processes, i. e., melting with total oxidation and melting without oxidation.

By the same token, it may be argued, the "white slag," rich to grayness with calcium-carbide, which is so often considered the "sine qua non," may actually be less efficient than a slag of lower CaC_2 content. By using a rolling white slag, like the foam of beer, one which falls to a powder and smells of acetylene, the metal tends to free itself both from gases and free oxides, while the few remaining oxides, if present at all, are taken care of during "degasification" with silicon, manganese, etc., some time prior to tapping. After all, the deoxidation is effected by means of the carriers, manganese, iron and silicon, the manganese and iron delivering their load of oxygen to the slag and returning for more, and the silicon staying in the slag as SiO_2. Therefore, the slag acts as a blanket to prevent oxidizing influences reaching the steel and as a reservoir of reducing material to take care of the oxygen carried by the manganese, iron and silicon. If the slag is sufficiently high in carbon or CaC_2 to perform these duties, nothing is gained by increasing the concentration of reducing elements, while a very real disadvantage is the carbon pick-up and the possibility that the elemination of hydrogen and nitrogen is slowed up.

The author does not touch on what may be called "final deoxidizers," such as aluminum. There has grown up the belief that the use of any such addition, and particularly aluminum, is "bad medicine," although it is

commonly known that they are almost universally used in making open hearth steels. Some tests conducted to determine the efficacy and desirability of these deoxidizers, including aluminum, magnesium, zirconium, calcium-silicide and other metals and alloys, resulted in the decision that (1) with a well-made heat the use of any deoxidizer in the furnace prior to tapping seemed to have little influence, either beneficial or detrimental, on the physical characteristics of the steel, (2) the use of metallic magnesium is to be advised against, as its action is explosively violent. However, the writer admits to a heretical feeling that a judicious quantity of aluminum added on a rod under the slag about five minutes before tapping, although unnecessary perhaps, frequently improves the heat and tends to eliminate the last removable vestiges of oxides and gases. Calcium silicide is an excellent deoxidizer for ladle use, in the rare occurrences when the melter deems such practice essential.

The subject of final deoxidizers brings to mind the remark of the English melter who, in reply to a question as to what he treated his steel with before teeming, replied, "We always treat our steel with consideration, only consideration."

Mr. Sisco, whose publications are now recognized, we believe, as the best existing works on electric furnace steel, is to be congratulated on the concise, yet comprehensive, presentation of his subject.

Written Discussion:—By H. A. Schwartz, National Malleable and Steel Castings Co., Cleveland.

The author has succeeded so admirably in presenting in concise form a complete description of the operation of an electric furnace in the making of steel, that any discussion cannot be much more than a repetition of what is already to be found in the paper itself.

Mr. Sisco has very wisely separated deoxidation from degasification by treating them under separate headings. This is a point well worthy of emphasis. An illustration from a kindred, though, perhaps distant, field may not be amiss.

Through the kindness of the Bureau of Standards, Louis Jordan has furnished us with trustworthy oxygen determinations on certain typical white cast irons. Even on air furnace metal which has become strongly oxidized, in the sense of being extremely low in manganese and silicon, and very wild, only the very small oxygen content of normal practice is found. In this same metal, quieted by manganese and silicon additions, very large oxygen contents, many times that of the metal poured before the additions, were found. Preliminary microscopic investigations suggests that this oxygen may be present as a constituent of sonims. Such metal is degasified, but not deoxidized except to the extent that we may wish to regard the sonims as no part of the alloy.

The so called "deoxidizing" agents here actually caused the retention of oxygen which would otherwise have escaped during freezing. Wildness is not evidence that the solid metal contains oxygen, nor quietness that it does not. Indeed, the reverse may be more nearly true if we consider that

wildness results from the liberation of oxygen as CO during freezing, while quietness may be merely the result of an addition which increased the solubility for oxygen compounds or converted oxygen present into chemically inert compounds.

M. A. GROSSMANN: I should like to discuss the phases of Mr. Sisco's paper that have to do with the use of silicon. The first statement made, or one of the first ones made by Mr. Sisco, had to do with the reaction between carbon monoxide and silicon whereby SiO_2 was formed and carbon liberated. Mr. McKnight has already referred to the fact that there is one other aspect under which the degasifying by silicon can be considered, and that is that metallic silicon increases the solubility of carbon monoxide gas in the steel. This latter view referred to by Mr. McKnight is widely held, and I do not know whether Mr. Sisco has any definite data showing which of these reactions is the correct one. It would be possible to determine this by allowing some "open" steel to solidify, the carbon monoxide passing off during the solidifying period, and then treating some of the same steel with metallic silicon and determining the difference in carbon content. If there is a reaction between carbon monoxide and silicon, naturally the steel that has been "killed" with metallic silicon will have a higher carbon content, because in the unkilled steel, carbon monoxide carried off the other carbon in solidifying.

Mr. Sisco also refers to the use of silicon to curb wildness. This is often done at the beginning of a heat, as he states. He says, however, that the silicon is retained permanently in the slag, implying that all of the silicon is retained in the slag. As a matter of fact, a certain amount of it is retained almost permanently in the metal. It is very difficult to eliminate the last traces of SiO_2 from electric furnace steel when wild steel has been killed.

Mr. Sisco also says ferrosilicon should not be added until the end of a heat. This is a statement with which we agree heartily, for the reason indicated a few moments ago, that silicon forms SiO_2, which is difficult to eliminate. There are certain conditions under which silicon may be added at the beginning of a heat to advantage, but in general it is better to leave the steel for an hour or longer under a deoxidizing slag and then use the silicon at the end as a degasifier, and final deoxidizer, as stated by Mr. Sisco.

You will notice in the log sheets that Mr. Sisco gives for two heats, that the one melted with complete oxidation, as he calls it, has silicon added at the beginning of the heat. The other, the heat melted with partial oxidation, is left under a carbide slag for a considerable time and the silicon added at the end of the heat. It should be remembered that the final product from these two heats will be quite different. The effect of the retained SiO_2 in the first heat will be very noticeable in the mechanical properties, and also in the microstructure. The second heat, the one melted with partial oxidation, is the one made under Mr. Sisco's recommended practice of leaving the steel under a carbide slag and then adding the silicon at the end of the heat.

Finally, Mr. Sisco refers to the manganese silicate rising with the slag, this manganese silicate being formed from the SiO_2, together with the manganese oxide. If the conditions are such that the manganese silicate can be

formed, and if there is sufficient mechanical agitation of the bath, this manganese silicate will rise to the surface, as indicated. However, this reaction of the manganese silicate rising to the slag takes place much better in the open hearth furnace than it does in the electric furnace. The agitation of the bath by the evolution of carbon monoxide in the open hearth furnace apparently permits the particles of manganese oxide and SiO_2 to come into contact much more favorably, and it is found that the SiO_2 actually is so removed under proper conditions in the basic open hearth furnace. This is difficult to accomplish in the electric furnace, however, and it is not well to rely on this reaction too much. As indicated before, the presence of SiO_2 would best be avoided by adding the silicon at the end of the heat rather than by depending on the silicate being fluxed out by oxides.

DR. B. EGEBERG: In his present paper Mr. Sisco deals with the quality of steels when melted in three different ways, with perfect oxidation, with partial oxidation, and with no oxidation at all. It is this part of the paper I want to discuss, and I want to add that I see it more from a metallurgist's than from a steel maker's standpoint.

Mr. Sisco takes the point of view that melting with complete oxidation is productive of only low-grade steels. Although he supports his theory very nicely and logically, my experience tells me that that cannot always be true. I am referring not only to steels in this country, but more to those from across, and I want to limit my discussion to two steels, a 0.80 per cent straight carbon steel and a chromium-nickel steel. The carbon steel was used for solid and hollow drill steels and was made in two grades, or what we at that time thought were two different grades. The one was worked with partial oxidation, and the other melted with complete oxidation. Every one of these heats was followed closely by making actual rock drilling tests before the heat was put into drills, hardness tests by rising temperatures were made in order to ascertain the highest possible quenching temperature by which a fine-grained fracture was still obtainable. These two methods of testing are the best ones I know of for the steel in question, but still it was impossible to establish any difference in performance between the steels melted, the one way or the other.

The chromium-nickel steel referred to was the regular low-carbon, high-nickel, high-chromium steel for case-hardening purposes. It is well known that this kind of steel should be melted with complete oxidation in order to bring the carbon content down to the desired amount. I have found from several steelmakers that this steel is the very best chromium-nickel steel they make, although it is here impossible to use the highly deoxidizing carbide slag, but the lime slag alone has to be relied upon in order to keep the carbon content down.

We have, then, in this case, according to Mr. Sisco, a highly oxidized bath and a slag that is not absolutely fitted for vigorous deoxidation, and still we obtain a superior steel. How is this possible, if Mr. Sisco's theories are right? I maintain that steel to be superior on the basis of transverse, static and impact toughness after suitable heat treatment. I have found this kind of steel to be less flaky and woody, and the relation between the longitudinal

and transverse toughness figures to be better for this than for any other chromium-nickel steel.

My experience, therefore, does not confirm Mr. Sisco's, and the explanation for this I believe is to be found in the base material. Time has shown that the quality obtained from the electric furnace stands in a certain relation to the scrap utilized. Generally speaking, the oxidizing heats have a lower quality scrap to start with, and I believe this factor to have just as much influence upon the quality of the final steel as has the difference in melting practice.

The oxidizing heats I have dealt with have all been made from a better charge than usual, and they show that high quality steel can be produced also when melting with perfect oxidation.

F. B. FOLEY: Mr. McKnight spoke prior to the last speaker on the subject of the reduction of silica. A number of years ago the late J. E. Johnson Jr. requested me to determine the free-running temperature of ferrosilicon. The results obtained seemed rather startling at the time.

I used an electric furnace in which I had two crucibles, one inside the other, the space between being filled with carbon. Each crucible was covered with a lid, and a thermocouple for measuring the temperature of the ferrosilicon was introduced through holes in the two lids. Time-temperature readings were taken throughout the heating, and when these indicated a point just a trifle higher than the melting point, I attempted to pour the metal to see if it would run freely. The metal came out in lumps, and flopped into the mold.

In a second attempt the ferrosilicon was heated to 1700 degrees Cent., well above the melting point, and this time the metal ran smoothly.

Upon examining the first metal I found the individual lumps coated on the outside with a black deposit, evidently carbon, and beneath it a whitish layer, probably silica. There was no such thing in the second cast.

I do not know that my interpretation of the phenomena is correct, but I assumed that the CO atmosphere within the crucible had oxidized the silicon at the lower temperature, coating the pieces with silica, and depositing carbon, and that at the higher temperature the CO gas reduced silica. It would seem if this were the proper interpretation, that temperature has a very great deal to do with the reduction of silica in furnace operation. Of course in the first experiment the silica was below its melting point and acted as an envelope about the molten ferrosilicon.

JEROME STRAUSS: A number of the previous speakers have referred to the practice of complete oxidation in the first stage of the electric process. Many of us, probably most of us, have heard about good, bad and rotten electric steel. We can find all kinds, although not so often outside of the steelmaker's plant as inside.

That the character of the scrap and also the nature of the oxidation period are of extreme importance, I believe no one will question. Ultimately, what it means is this: that the nature and distribution of the oxidized components at the time of removal of the first slag, and the manner in which they are reacted upon by the second slag (or its intermediate reaction products) govern the quality of the finished steel. For that reason, wherever possible,

it would seem well to avoid dirty, rusty and small size scrap in large quantity, and also to avoid too severe oxidation during the first period of the process.

In the second period of the process it may sometimes become necessary, due to the manner in which the first period has been conducted, to carry the reducing slag for an excessively long time, and I would leave with you this thought, that where it is necessary for that second slag to do an excessive amount of work, one experiences trouble from the melting of the roof, due to the high temperature combined with the long time. Troubles arise also from another source that most steelmakers know about, but to which they have not given so much attention. This is that the bath is not only in contact with the slag, but also with a bottom that contains a variable amount of iron oxide, and while reactions are taking place at the top surface of that bath, there are also reactions taking place at the bottom surface. This often becomes an extremely important factor.

RADCLYFFE FURNESS: I was glad to hear Mr. Strauss mention the bottom condition of the electric furnace. I do not think there is an electric melter, myself included, who ever pays the attention that should be paid to the fact that there is not sufficient exchange between the bottom and the top layers of metal in the electric furnace. I do not think it is ever recognized. We talk about the electric furnace being more thoroughly deoxidizing than either of the open hearths. It is, but it misses one great thing: there is not the exchange between the top and the bottom metal that there should be. We may have the top in perfect condition; we do not know the condition of the bottom metal. I do not think that any of us recognize this sufficiently. I do not think we go into it carefully enough—we all very carefully sidestep it. We pretend that it is all right. It is not. The electric furnace cannot be classed as the perfect tool that we would like to believe it to be until the condition mentioned is overcome.

Further, both open hearth furnace men and electric furnace men have talked about desirability of a "good" charge. I like a good charge. I believe in a good charge, because it speeds up melting, but by no possible stretch of my imagination or experience can I picture that conditions other than chemical composition can affect the finished product. I cannot believe that the physical characteristics of the scrap exist in any way in the finished product. It is true that rusted scrap takes longer to get in condition because it is exactly the same as added ore. I cannot believe, that any characteristics in the scrap can carry through and show in the finished product. I most earnestly request that anyone present, both for my good and for the good of the society, enlighten us as to any evidence that proves that the above is a fact.

CHAIRMAN MATHEWS: Any more discussion?

MEMBER: All this discussion on the electric furnace seems to be on the basic practice. Is there anybody here who has had any experience in acid electric furnace practice? I would like to hear something on that.

C. T. PATTERSON: In acid electric furnace practice we have found reduction of the silicon in the slag, and perhaps in the bottom, to silica in the

metal, and this reaction proceeds with increased rapidity as the temperature rises. As much as a half of one per cent of silicon has been reduced in holding a heat half an hour longer than the usual time for tapping.

CHAIRMAN MATHEWS: Any further questions or discussion? I do not want to hold you here longer than necessary, but we want you all to have a chance to say what you want to say, or to ask questions. The session has been a very interesting one, and the authors are entitled to our best thanks for the work they have put on their processes and their papers describing the various processes. I am surprised that there is not more difference of opinion about the relative merits of these processes, because the authors all claim some distinctive merits.

Written Discussion: By R. H. Patch, Midvale Co., Philadelphia.

In connection with the rapid increase in electric steel production, it is interesting to note that production of alloy steel castings has also increased rapidly during the past few years. Thus, in 1923 and 1924, approximately 29,000 tons were produced during each year. This is a remarkable figure when one considers that in 1914 only 340 tons were made, and it was not until 1919 that over 5,000 tons of electric steel alloy castings were produced. This is an excellent index of the increased appreciation during the past decade of the possibilities to be gained by heat treatment of castings.

The acid electric furnace is used almost wholly for castings: or perhaps it is better to say most electric steel castings are produced by the acid process. The reason for this is due to the fact that much cheaper supervision is required on account of the fact that there is no refining possible. In fact, it has been known to happen that heats have been made for castings which had not enough slag to cover the surface of the metal. Therefore, while it is possible to produce high-grade acid electric castings, the very nature of the process offers a great temptation to sloppy practice, which is not possible in the basis electric furnace.

The relative advantages of graphite and amorphous electrodes are always a topic for fruitful discussion. Each kind has its adherents. Personally, I favor the carbon electrodes because of the feeling that one of the chief disadvantages of the electro furnace is the great concentration of heat, whereas in the open hearth furnace the flame plays practically over the whole surface of the slag. In the electric furnace, there is great opportunity for local overheating, and therefore I prefer to have as much of the surface of the bath covered by electrodes as is reasonably possible. Thus during the melting, that portion in back of the tapping spout frequently remains fast to the front bank for some time after the balance of the heat is melted.

The bottom, according to Mr. Sisco, is made of ground magnesite and basic slag. It is a perfectly good practice to make a bottom of calcined dolomite. We have had bottoms at Midvale made of this material which have given a life of over 2000 heats, and probably would be lasting yet except for the fact that it was impossible, on account of operating conditions, to keep the furnace melting continuously.

In the charging of the heat, the skill of the melter comes into play to a

very considerable degree, for, according to the way the heat is charged, it is possible to vary the melting time by as much as an hour in a 5-ton furnace. The shape of the bottom also plays no inconsiderable part in the melting of the charge. A bottom with high sides and deep centers is one to be avoided. A bottom shaped like a saucer has been found to be best for fast melting in our practice.

Under the heading "control of oxidation in melting" three variations in melting practice are considered:

First—Complete oxidation.

Second—Partial oxidation

Third—Melting without oxidation.

Mr. Sisco states that the advantage of the first method is that dirty and rusty scrap can be used, which is not possible in the second method of partial oxidation. The logic of this is not perfectly plain, as by using some carburizing medium, e. g., coal or pig, with the charge, it is possible to use rusty scrap in the second method, and thus avoid the addition of any ore. In the manufacture of high carbon steel, we have been unable to show that the previous condition of the scrap used had any effect on the final product, provided one does not allow the carbon in the bath to fall too low during the melting.

On the contrary, we have made heats according to the third method, and these heats have given greater trouble in fabricating than heats made in the regular manner. In fact, it is our belief that melting by the second of the first two methods is preferable, owing to the fact that under these conditions, the bath is livelier, and greater opportunity is offered for the metal to be more thoroughly stirred up, and thus bring the preliminary refining reactions to completion.

Mr. McKnight of the International Nickel Company found that he was unable to make high silicon steels under a reducing slag without the steels raising. He was forced to melt with use of ore. In suggesting an explanation, Mr. Grossmann of the United Alloys Steel Corporation brought out that fact that silicon acts to promote the solubility of the carbon monoxide in the steel.

Mr. Sisco emphasises the importance of carrying a carbide slag in order to complete the deoxidation of the bath. It has been my experience that there is a danger here which should be mentioned. If the carbide in the slag rises to a figure around 2 per cent or over, great difficulty is experienced in keeping the metal hot, and this danger far outweighs the one resulting from the "picking up" of carbon. In our practice the latter is an extremely rare occurrence.

Mr. Sisco states that the basic electric furnace offers the opportunity of adding alloy additions one half hour or more before tapping. This is true, but our experience, carefully followed up over a considerable period of time, has failed to show that the quality of the steel is improved by extended holding of the heats after the alloy additions have been made. In fact, results indicate that steel of first quality is produced by tapping as soon as additions are thoroughly melted.

Mr. Sisco very properly emphasizes the necessity of correct pouring practice. We have repeatedly found that steel which, before tapping, was perfectly free from slag inclusions, upon examination of the ingots showed the metal to

be "dirty." In fact, too great stress cannot be exerted upon the producing unit, for the maintenance of clean equipment, e. g., ladles, molds, etc., and clean bottoms and runners in the case of bottom pouring. We believe that more heats are spoiled after the metal leaves the furnace than from poor practice in the furnace. In fact our experience would indicate that the pouring practice, including the pit practice, requires most careful supervision. For that reason, we insist that the melter himself pours off the heat, and thus carry his responsibility through to the completion of the heat.

Too great ferrostatic pressure from the metal in the ladle upon the stream is also a fruitful source of inclusions, due to splashing in the mold. Even with all these factors under control, one is still always faced with the possible and probable oxidation of the metal stream to a greater or less degree, and concerning the control of which one is almost helpless. If one could only run a tube from the metal in the furnace into the mold, and maintain it just above the surface of the metal during the pouring, we would have an ideal condition for the production of clean metal.

F. T. Sisco: The writer greatly appreciates the discussion of the paper by Messrs. McKnight and Schwartz, especially as both gentlemen brought out some interesting facts regarding degasification. Degasification in the electric furnace is imperfectly understood. The consensus of opinion in regard to the action of silicon in quieting wildness seems to be evenly divided into two radically different schools. One school looks upon degasification as the result of a purely chemical reaction

$$2\,CO + Si \rightarrow SiO_2 + 2C$$

by which the carbon monoxide reacts with silicon. We might say that the dissolved or occluded gas is destroyed and is replaced by silicon dioxide, Sio_2. The other school maintains that the carbon monoxide gas is not actually eliminated; the idea seems to be that silicon by some obscure physical process increases the solubility of the steel for CO gas. Probably the basis of this line of thought is that a liquid solution of silicon (iron-silicide) in iron will dissolve more gas than molten iron free from silicon.

In writing the paper, the writer made an effort to confine the discussion of electric furnace melting to the best present day practice, hence a critical discussion of deoxidation and degasification, especially of conflicting theories, was avoided. The writer is now attempting to work out a logical theory of this phase of electric steel making on the assumption that deoxidation and degasification may be explained by means of the principles of colloid chemistry. It has seemed more logical in the past to consider degasification as a chemical process resulting from the above reaction instead of assuming that the silicon does not actually eliminate the CO gas but simply increases the solubility of the gas in the iron. Mr. Schwartz has brought this out in his discussion.

Mr. McKnight makes an interesting assumption that nitrogen and hydrogen may be present in amounts sufficient to cause trouble. While this is entirely possible, it has long been thought to be improbable. It is hard

(Discussion Concluded on Page 869)

EFFECT OF COLD WORKING ON ENDURANCE AND OTHER PROPERTIES OF METALS, PART 1[1]

By D. J. McAdam Jr.

Abstract of Parts I and II

Part I of this paper presents a number of graphs illustrating the effect of cold working on tensile strength, yield point, shearing strength, yield ratio, shear ratio, and Meyer hardness indices. The possible relationship between the effect of cold working on these properties and the effect on endurance limit is discussed.

Other graphs illustrate the effect of cold working on rotating-cantilever endurance limits of copper, bronze and brass. The effect of internal stress is discussed.

Effect of cold working on alternating-torsion endurance limit of nickel is illustrated and discussed.

Part II presents a number of graphs illustrating the effect of cold working on ductility and on some strength values, the calculation of which depends on ductility values. Results are plotted with "percentage increase in tensile strength due to cold working" as abscissas, and relationship between the various curves is discussed.

History of Previous Investigation at the Naval Engineering Experiment Station

In a series of papers on "Endurance Properties of Alloys of Nickel and Copper"[3, 4, 5] the writer discussed the effect of cold working on endurance properties of nickel and some of its alloys with copper. Investigation of these alloys showed that moderate cold working increased the endurance limit in proportion to the increase in tensile strength due to cold working. Severe cold working of nickel, however, increased the endurance limit less than in proportion to the increase in tensile strength.

In the paper on "Endurance Properties of Alloys of Nickel

[1]This paper is published by permission of the Secretary of the Navy.

[3]D. J. McAdam Jr. "Endurance Properties of Alloys of Nickel and of Copper," Part I, Transactions, American Society for Steel Treating, January, 1925.

[4]D. J. McAdam Jr. "Endurance Properties of Alloys of Nickel and of Copper," Part II, Transactions, American Society for Steel Treating, February 1925.

[5]D. J. McAdam Jr. "Endurance Properties of Alloys of Nickel and of Copper," Part III, Transactions, American Society for Steel Treating, May 1925.

A paper presented before the Cleveland Convention of the Society, September, 1925. The author, D. J. McAdam, Jr., member A. S. S. T., is metallurgist with the U. S. Naval Engineering Experiment Station, Annapolis, Maryland.

and of Copper, Part III,"[5] curves were plotted showing the relation of endurance limit and other physical properties of nickel to percentage increase in tensile strength due to cold working. In Fig. 10 of that paper it was shown that the curve of endurance limits for nickel apparently begins to approach a horizontal direction as the increase of tensile strength due to cold working reaches about 50 per cent. In the same figure it was shown also that the curve of "shear ratios" (ratios of shearing strength to tensile strength) apparently approaches a horizontal direction as the increase in tensile strength due to cold working reaches about 50 per cent. This similarity of form of the two curves, which it was admitted might be only a coincidence, led to further investigation of the effect of cold working on the "shear ratio" and on other physical properties. It was hoped that some definite relationship might be discovered between the effect of cold working on the endurance limit and its effect on some other physical properties.

Material for New Investigation

For investigation of the effect of cold working on endurance and other physical properties, plate, sheet and bar metal was furnished by manufacturers. The International Nickel Company, the American Brass Company, the Scovill Manufacturing Company, the Bridgeport Brass Company, the Aluminum Company of America and the American Rolling Mill Company cooperated in this investigation by furnishing cold-worked material well adapted for the purpose. The thickness of the plates and sheets varied from 0.025 to 0.3 inch, and they had received various degrees of cold working. In Table I each alloy is designated by a combination of letters and the chemical composition is given. Details of annealing treatment at the Naval Experiment Station are given in Table II.

Investigation of Effect of Cold Working on Tensile and Shear Properties

For most of the plate and sheet material the exact amount of reduction in thickness by cold working was not known. Nevertheless, it was thought that information of value might be obtained by plotting percentage increases in tensile strength due to cold

Table I
Chemical Composition

Material	Material Designation	Percentage C	Ni.	Cu.	Sn.	Al.	Zn.	Fe.	Mn	Pb	Si.	P	S	Mg.
Nickel, Cold-Rolled	**DB	0.092	98.85 By Diff.	0.14	....	....	....	0.60	0.27	....	0.01	....	0.016	....
Monel Metal, Cold-Rolled	*DC	0.17	70.24	27.28	....	....	....	2.12	0.35	less than 0.01	0.17	....	0.021	....
Copper, Cold-Rolled	**DJ	....	....	....	....	....	....	0.007	....	less than 0.001	....	....	....	....
69:31 Brass, Cold-Rolled	+DO	....	....	69.05	none	....	30.94	0.05	....	less than 0.01	....	....	....	....
66:34 Brass, Cold-Rolled	DF	....	....	65.86	none	....	33.87	0.03	....	0.17	....	....	....	....
Alumium, Cold-Rolled	**DE	....	....	0.18	0.05	98.98 By Diff.	....	0.52	.008	....	0.20	....	....	0.07
Aluminum-Manganese Alloy, Cold-Rolled	*DH	....	....	0.22	0.04	97.51 By Diff.	....	0.59	1.00	....	0.34	....	....	0.30
Ingot-Iron, Rolled	DQ	.044	....	....	....	....	....	99.90 By Diff.	.025	....	.003	.002	.025	....
Ingot-Iron, Rolled	BT	.040	....	....	....	....	....	99.90 By Diff.	.025	....	.004	.002	.029	....
Copper, Electrolytic, Cold-Rolled	DI	....	....	....	....	....	....	0.008	....	less than .001	....	....	....	....
95:5 Bronze, Cold-Rolled	DG	....	....	95.57	4.05	....	none	0.09	....	less than 0.01	....	0.39	....	....
89:11 Bronze, Cold-Rolled	DD	....	....	89.39	10.60	....	none	0.08	....	less than 0.01	....	0.13	....	....
81:19 Brass, Cold-Drawn	DN	....	....	81.00	none	....	19.06	0.05	....	less than 0.01	....	....	....	....
70:30 Brass, Cold-Rolled	DM	....	....	70.08	none	....	29.99	0.05	....	less than 0.01	....	....	....	....

Unless otherwise indicated each value is average of two determinations.
* Average of six determinations. ** Average of eight determinations. + Average of four determinations.

TABLE II

Annealing Treatment

Material	Material Designation	Heated to Degrees Fahr.	Time Held, Min.	Cooled in
Nickel, Cold-Rolled	DBc-16	1600	45	Furnace
Monel Metal, Cold-Rolled	DCb-16	1600	45	Furnace
Copper, Cold-Rolled	*DJh	....	..	
69:31 Brass, Cold-Rolled	*DOf	....	..	
66:34 Brass, Cold-Rolled	DFd-8	800	30	Air
Aluminum, Cold-Rolled	*DEi	....	..	
Aluminum-Manganese Alloy, Cold-Rolled	DH-9	900	45	Furnace
Aluminum-Manganese Alloy, Cold-Rolled	DHa-9	900	45	Furnace
Aluminum-Manganese Alloy, Cold-Rolled	DHb-9	900	45	Furnace
Ingot Iron, Rolled	*BT	....	..	
Copper, Cold-Rolled	DI-3.0	300	60	Air
Copper, Cold-Rolled	DI-4.0	400	60	Air
Copper, Cold-Rolled	DI-5.0	500	60	Air
Copper, Cold-Rolled	DI-6.0	600	60	Air
Copper, Cold-Rolled	DI-8.0	800	60	Air
Copper, Cold-Rolled	DI-12.0	1200	60	Furnace
95:5 Bronze, Cold-Rolled	DG-4.0	400	60	Air
95:5 Bronze, Cold-Rolled	DG-5.0	500	60	Air
95:5 Bronze, Cold-Rolled	DG-6.0	600	60	Air
95:5 Bronze, Cold-Rolled	DG-7.0	700	60	Air
95:5 Bronze, Cold-Rolled	DG-9.0	900	60	Air
95:5 Bronze, Cold-Rolled	DG-10.5	1050	60	Air
95:5 Bronze, Cold-Rolled	DG-12.0	1200	60	Furnace
89:11 Bronze, Cold-Rolled	DD-11.0	1100	60	Furnace
89:11 Bronze, Cold-Rolled	DD-12.0	1200	60	Furnace
81:19 Brass, Cold-Drawn	DN-3.0	300	60	Air
81:19 Brass, Cold-Drawn	DN-4.5	450	60	Furnace
81:19 Brass, Cold-Drawn	DN-6.0	600	60	Air
81:19 Brass, Cold-Drawn	DN-7.0	700	60	Air
81:19 Brass, Cold-Drawn	DN-8.0	800	60	Furnace
81:19 Brass, Cold-Drawn	DN-9.0	900	60	Air
81:19 Brass, Cold-Drawn	DN-10.0	1000	60	Furnace
81:19 Brass, Cold-Drawn	DN-12.0	1200	60	Air
70:30 Brass, Cold-Rolled	DM-2.0	200	60	Air
70:30 Brass, Cold-Rolled	DM-3.0	300	60	Air
70:30 Brass, Cold-Rolled	DM-4.0	400	90	Furnace
70:30 Brass, Cold-Rolled	DM-4.5	450	90	Furnace
70:30 Brass, Cold-Rolled	DM-5.0	500	90	Furnace
70:30 Brass, Cold-Rolled	DM-6.0	600	60	Air
70:30 Brass, Cold-Rolled	DM-7.0	700	60	Air
70:30 Brass, Cold-Rolled	DM-8.0	800	60	Furnace
70:30 Brass, Cold-Rolled	DM-9.0	900	60	Air
70:30 Brass, Cold-Rolled	DM-12.0	1200	60	Furnace

* Fully annealed by manufacturer, temperature not known.

Unless otherwise indicated each value is average of two determinations.
* Average of six determinations. ** Average of eight determinations. + Average of four determinations.

working as abscissas, and various tensile and shear properties as ordinates. For two kinds of material the exact amount of reduction in thickness by cold working was known, and the results could be plotted with ratio of original to final thickness as abscissas.

Tension test specimens of bar material with few exceptions were standard specimens 0.505 inch in diameter and 2 inches in gage length. A few specimens were of smaller diameter. The tension test specimens of plate and sheet material were 1 inch wide, the gage length was 4 inches, and the thickness was the full thickness of plate or sheet. Tension test results obtained with plate and sheet material are not given in tabular form. Tension test results obtained with bar material are given in Table III and in previous papers.[3, 4, 5]

Shear tests were made by the "double shear" method. The dies were sharp-edged and with 0.001 inch clearance on each side. Specimens of bar material were cylindrical, and the diameter was either ¼ or ½ inch.

Relationship of tensile and shear properties of various metals and alloys to degree of cold working is illustrated graphically in Figs. 1 to 14 inclusive. In Figs. 1 and 2, abscissas represent ratio of original thickness to thickness after cold working. In Figs. 3 to 14 inclusive, abscissas represent percentage increase of tensile strength due to cold working. Ordinates represent either strength of the metal as determined in various ways, or ratios of two such strength values. Figs. 1 and 2 show the effect of cold working on nickel and monel metal sheet. Abscissas represent ratio of original thickness to final thickness. As shown in these figures, both tensile and shearing strength at first increase rapidly. With increase in degree of cold working, however, the rate of increase in strength decreases rapidly. The ratio of shearing strength to tensile strength (shear ratio) at first decreases rapidly. With increase in degree of cold working, however, the shear ratio decreases less and less rapidly.

Figs. 3 and 4 illustrate on a different scale the same results that are illustrated in Figs. 1 and 2. Since in Figs. 3 and 4 abscissas represent percentage increase in tensile strength due to cold working, the upper line representing tensile strength is necessarily straight. Experimental points have not been marked on this line. As shown in Figs. 3 and 4, the experimental points

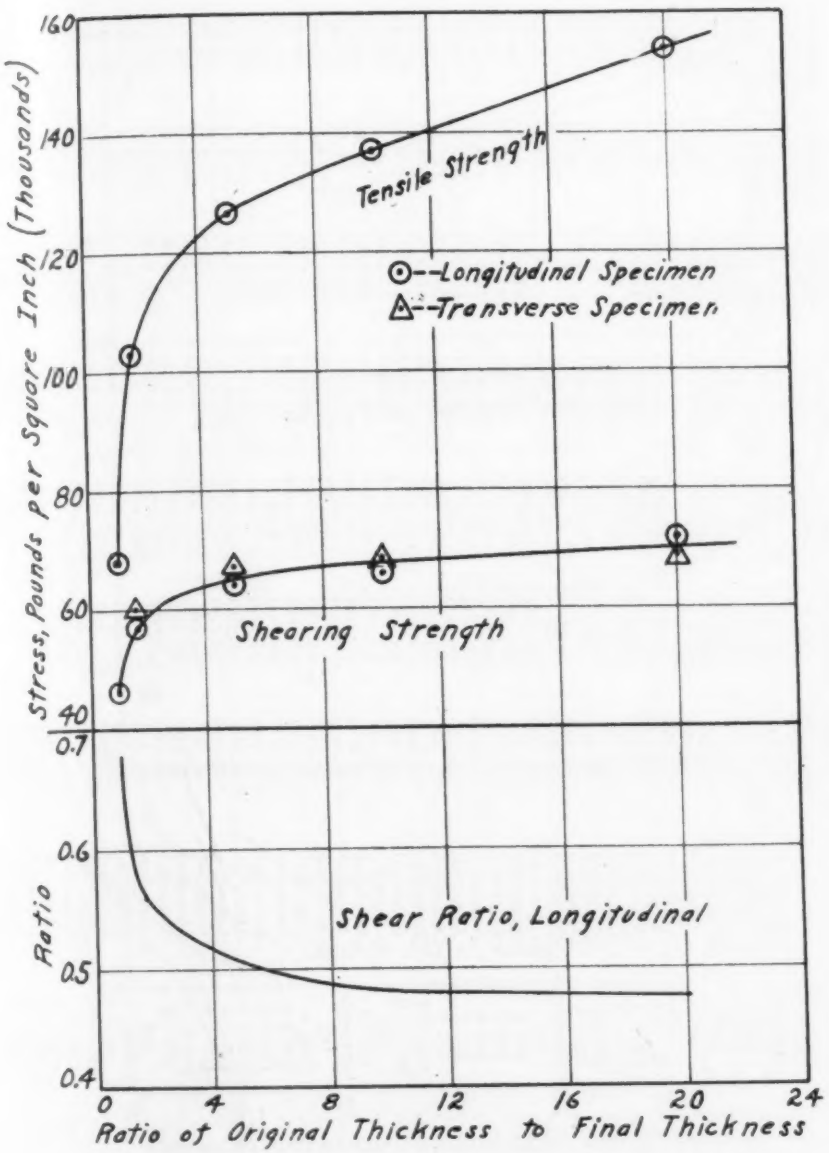

Fig. 1—Effect of Cold Working on Properties of Nickel Sheet, Material DB.

representing shearing strength fall on a straight line. The bottom curve in these figures represents the ratio of shearing strength to tensile strength (shear ratio). The next lowest curve represents ratio of yield point to tensile strength (yield ratio). It will be noticed that the yield ratio rises rapidly to a maximum value and then remains nearly constant until a high degree of cold working has been reached. The curve representing shear ratio gradually approaches a horizontal direction, but evidently would not

Table III
Tension Test Results—Bar Material

Material	Material Designation	Condition	Tensile Strength, Lb. Per Sq. In.	Johnson's Limit, Lb. Per Sq. In.	Proof Stress, Lb. Per Sq. In.	Elastic Limit, Lb. Per Sq. In.	Proportional Limit, Lb. Per Sq. In.	Elongation in 2 In., Per Cent	Reduction of Area, Per Cent
Ingot Iron, Rolled	DQ	As Received	*62,400	*40,500	*44,500	*22,000	*22,000	*17.0	*65.0
Ingot Iron, Rolled	DQa	As Received	*60,900	*43,500	*42,500	*30,000	*28,500	*15.5	*67.0
Ingot Iron, Rolled	DQb	As Received	*58,200	*42,500	*43,500	*38,500	*32,000	*16.0	*69.0
Ingot Iron, Rolled	BT	Annealed	*42,500	*25,000	.....	.....	*12,000	*49.0	*76.5
Copper, Cold-Rolled	DI	As Received	52,000	33,500	21,500	11,000	10,000	13.0	50.0
Copper, Cold-Rolled	DI-3.0	Annealed	*53,000	*31,000	*25,000	*13,000	*10,000	*12.0	*52.5
Copper, Cold-Rolled	DI-4.0	Annealed	51,000	*28,000	*24,000	*12,000	* 8,000	*16.5	*53.0
Copper, Cold-Rolled	DI-5.0	Annealed	*34,700	+	* 4,000	* 2,500	+	*52.0	*72.5
Copper, Cold-Rolled	DI-6.0	Annealed	*33,900	+	* 4,500	* 3,000	+	*58.0	*72.5
Copper, Cold-Rolled	DI-8.0	Annealed	*33,100	+	* 3,500	* 2,000	+	*52.5	*70.0
Copper, Cold-Rolled	DI-12	Annealed	32,100	+	3,700	2,300	+	57.5	71.8
95:5 Bronze, Cold-Rolled	DG	As Received	55,800	33,500	31,500	25,000	23,000	47.5	79.0
95:5 Bronze, Cold-Rolled	DG-4	Annealed	*56,100	*29,000	*27,000	*24,000	*24,000	*47.0	*73.5
95:5 Bronze, Cold-Rolled	DG-5	Annealed	*55,000	*30,000	*32,000	*29,000	*25,000	*48.0	*77.5
95:5 Bronze, Cold-Rolled	DG-6	Annealed	*54,000	*28,000	*30,000	*24,000	*18,000	*50.0	*79.5
95:5 Bronze, Cold-Rolled	DG-7	Annealed	*54,250	*29,000	*28,000	*23,000	*23,000	*55.0	*76.5
95:5 Bronze, Cold-Rolled	DG-9	Annealed	*51,800	*21,000	*20,500	*17,000	*15,000	*61.0	*79.0
95:5 Bronze, Cold-Rolled	DG-105	Annealed	*48,500	*18,000	*18,000	*14,000	*14,000	*66.0	*76.6
95:5 Bronze, Cold-Rolled	DG-12.0	Annealed	48,100	17,800	17,800	12,500	11,500	70.8	80.5
89:11 Bronze, Cold-Rolled	DD	As Received	82,800	50,000	46,000	39,500	38,000	37.8	63.0
89:11 Bronze, Cold-Rolled	DD-11	Annealed	67,600	28,500	28,300	*27,000	24,500	70.0	72.0
89:11 Bronze, Cold-Rolled	DD-12	Annealed	*65,800	*22,000	*23,500	*20,000	*13,000	*74.5	*73.0
81:19 Brass, Cold-Drawn	DN	As Received	76,500	46,500	40,000	30,500	21,000	16.0	64.8
81:19 Brass, Cold-Drawn	DN-3	Annealed	*77,500	*50,000	*51,000	*44,000	*24,000	*14.5	*64.5
81:19 Brass, Cold-Drawn	DN-4.5	Annealed	*80,500	*49,600	*45,600	*33,700	*27,700	*15.0	*63.6
81:19 Brass, Cold-Drawn	DN-6.0	Annealed	*50,000	*15,500	*17,500	*13,500	*13,500	*37.5	*69.5
81:19 Brass, Cold-Drawn	DN-7.0	Annealed	*49,000	*16,000	*18,000	*15,000	*13,000	*56.5	*75.5
81:19 Brass, Cold-Drawn	DN-8.0	Annealed	*48,500	*16,000	*17,000	* 9,000	* 9,000	*59.5	*78.5
81:19 Brass, Cold-Drawn	DN-9.0	Annealed	*45,800	*14,000	*15,000	* 7,000	* 7,000	*65.0	*79.5
81:19 Brass, Cold-Drawn	DN-10.0	Annealed	44,000	11,500	11,800	8,300	7,500	64.3	80.0
81:19 Brass, Cold-Drawn	DN-12	Annealed	*43,200	* 9,000	*10,000	* 6,000	* 6,000	*70.5	*82.3
70:30 Brass, Cold-Rolled	DM	As Received	**73,200	+	**20,000	**11,700	+	**20.0	**46.3
70:30 Brass, Cold-Rolled	DM-2	Annealed	*75,300	*35,000	*31,000	*19,000	*18,000	*18.0	*48.0
70:30 Brass, Cold-Rolled	DM-3	Annealed	*74,000	*51,000	*50,000	*41,000	*27,000	*19.5	*51.5
70:30 Brass, Cold-Rolled	DM-4.0	Annealed	*74,500	*52,000	*51,000	*44,000	*26,000	*15.0	*41.5
70:30 Brass, Cold-Rolled	DM-4.5	Annealed	*72,800	*49,000	*53,000	*45,000	*32,000	*18.0	*47.5
70:30 Brass, Cold-Rolled	DM-5.0	Annealed	**73,400	**48,000	**51,000	**43,300	**35,600	**17.7	**48.5
70:30 Brass, Cold-Rolled	DM-6.0	Annealed	*60,500	+	*24,000	*14,000	+	*37.0	*55.5
70:30 Brass, Cold-Rolled	DM-7.0	Annealed	*54,000	+	*20,000	*12,000	+	*55.0	*64.5
70:30 Brass, Cold-Rolled	DM-8.0	Annealed	*53,600	+	*20,500	*12,000	+	*56.5	*64.3
70:30 Brass, Cold-Rolled	DM-9.0	Annealed	*54,800	*21,500	*21,000	* 7,000	* 7,000	*54.5	*63.5
70:30 Brass, Cold-Rolled	DM-12	Annealed	45,000	+	9,800	5,800	+	72.3	66.0

Unless otherwise indicated each value is average of two determinations. * One determination only. ** Average of three determinations.
+ Stress-strain graph is curved from origin.

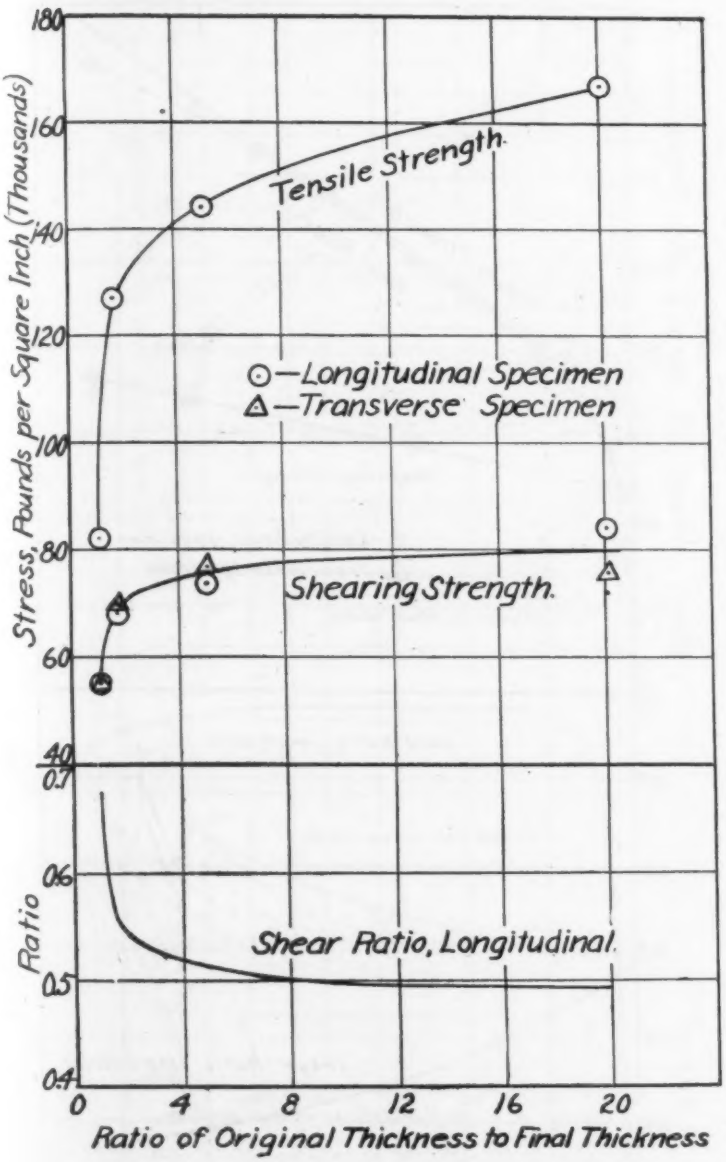

Fig. 2—Effect of Cold Working on Properties of Monel Metal Sheet, Material DC.

become nearly horizontal until the degree of cold working has become excessive. The approach of this curve to a horizontal direction is less abrupt than is indicated in Fig. 10 of a previous paper.[5]

Figs. 5, 6 and 7 show the effect of cold working on tensile and shear properties of sheet copper, aluminum and an aluminum-manganese alloy. Experimental values for yield point and shearing strength are marked on each of these graphs. As shown in Figs. 6 and 7, yield points and shearing strength values are prac-

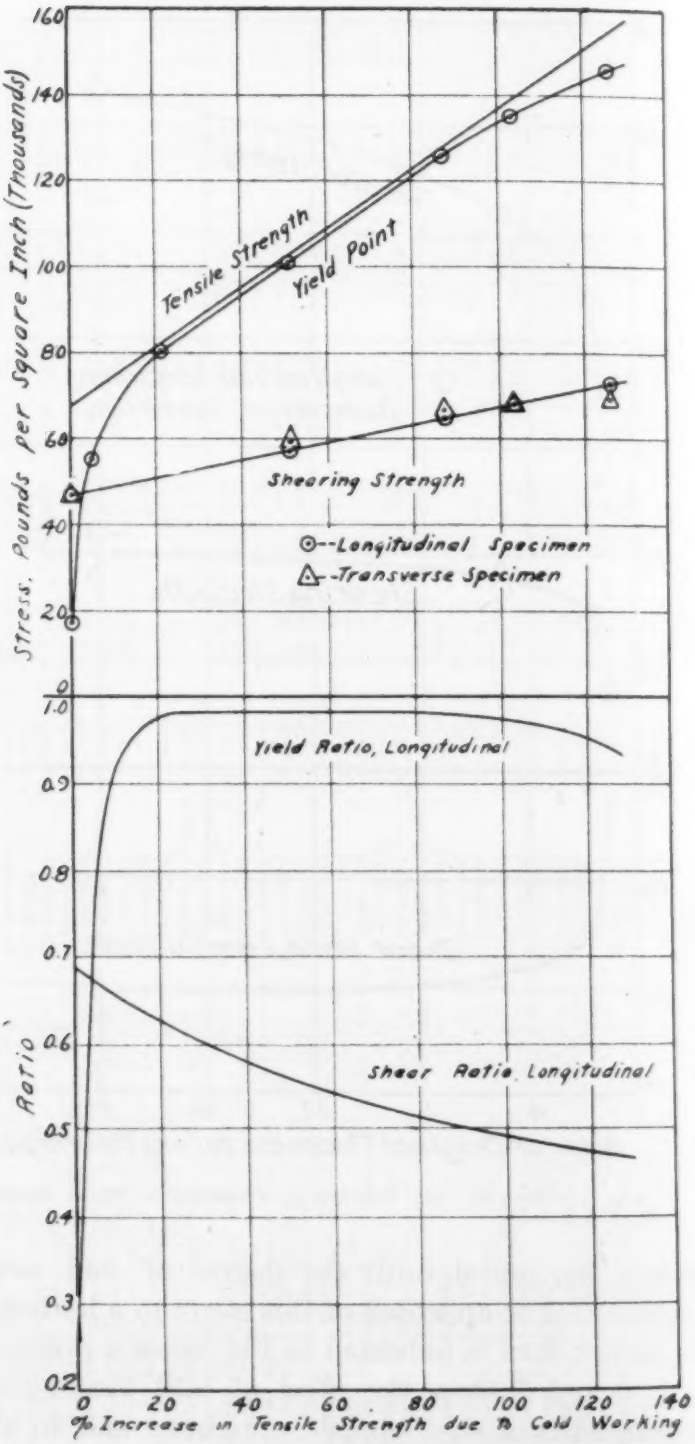

Fig. 3—Effect of Cold Working on Properties of Nickel Sheet, Material DB.

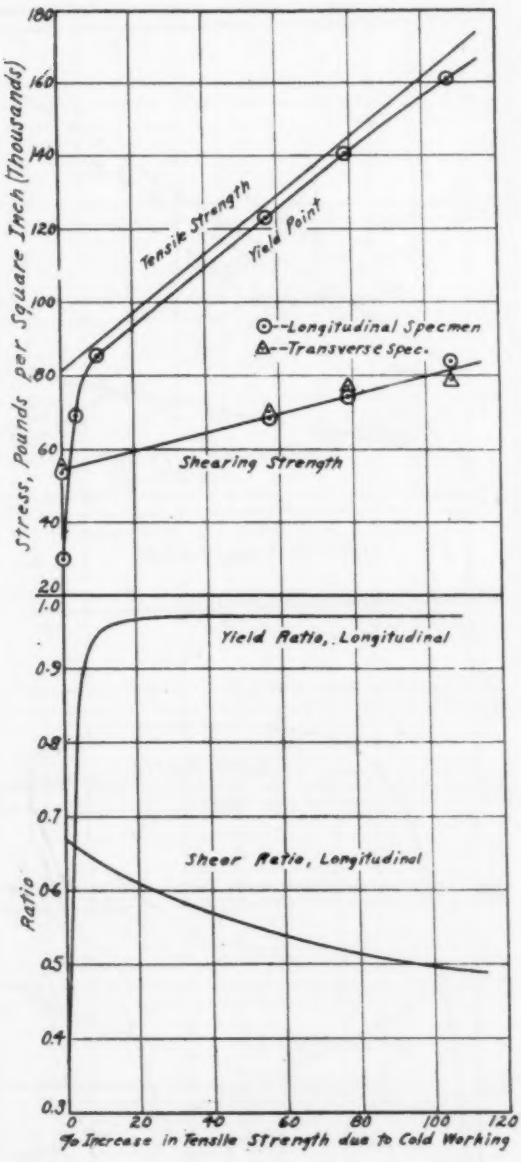

Fig. 4—Effect of Cold Working on Properties of Monel Metal Sheet, Material DC.

tically the same whether they are obtained with longitudinal or transverse specimens. The same is true of tensile strength, although results of individual determinations of this property are not indicated in the figures. Shearing strength relationship for each of these metals is illustrated by a straight line drawn through experimental points. The forms of the yield ratio and shear-ratio curves in each of these figures are similar to the forms of the corresponding curves in Figs. 3 and 4.

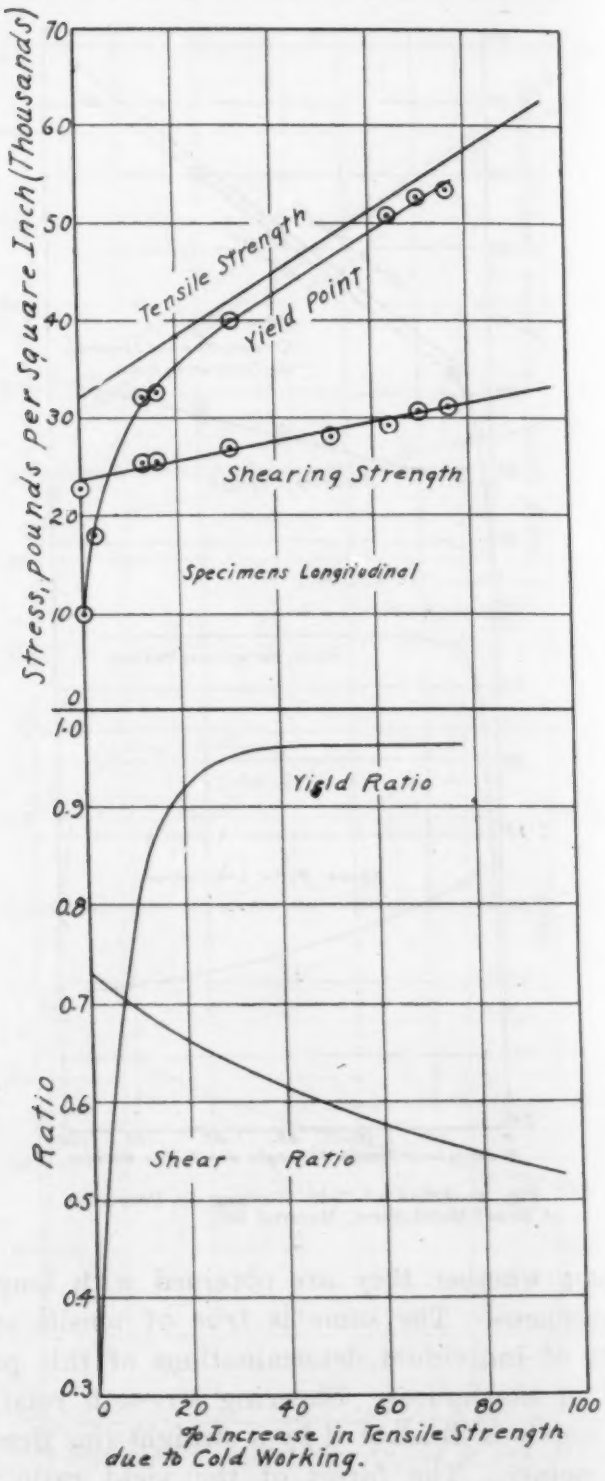

Fig. 5—Effect of Cold Working on Properties of Copper Sheet, Material DJ.

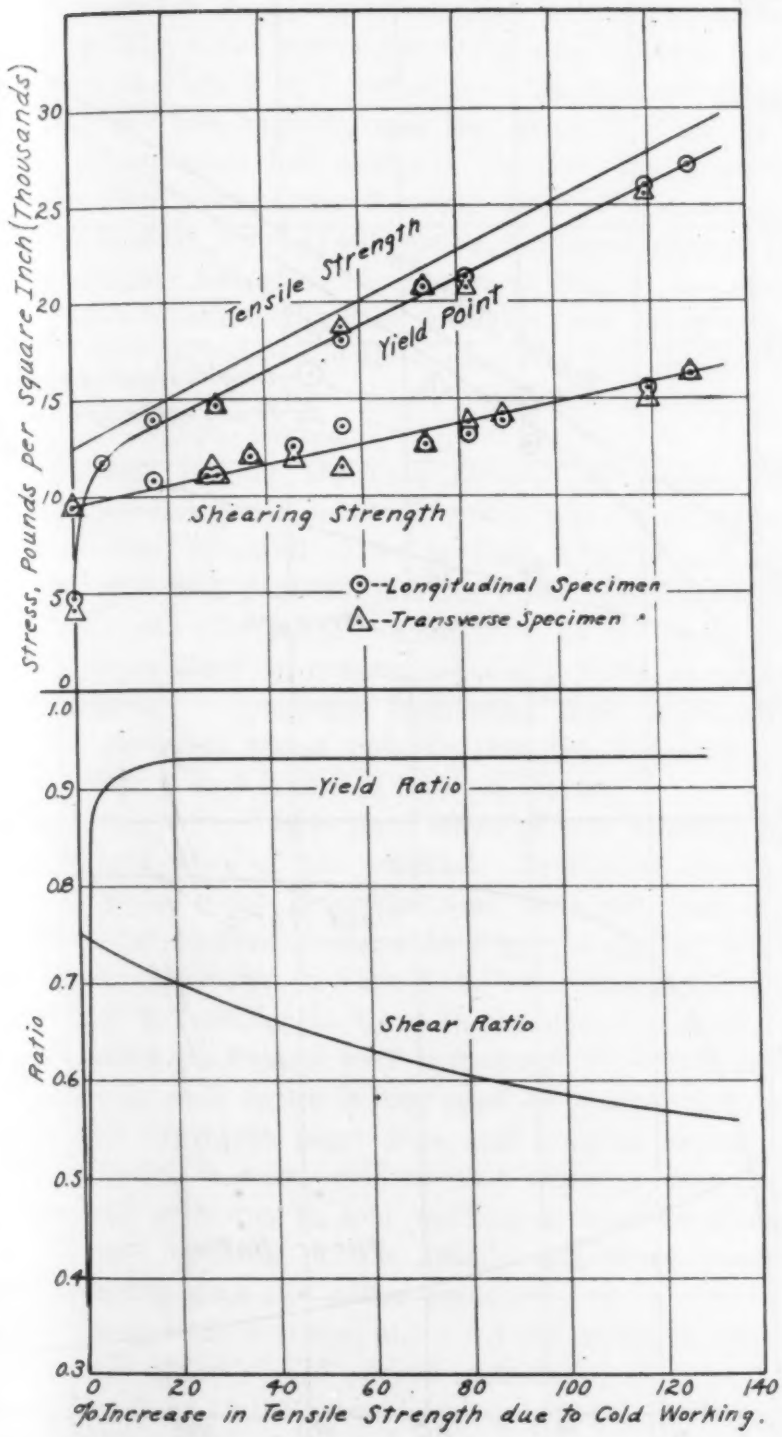

Fig. 6—Effect of Cold Working on Properties of Aluminum Sheet, Material DE.

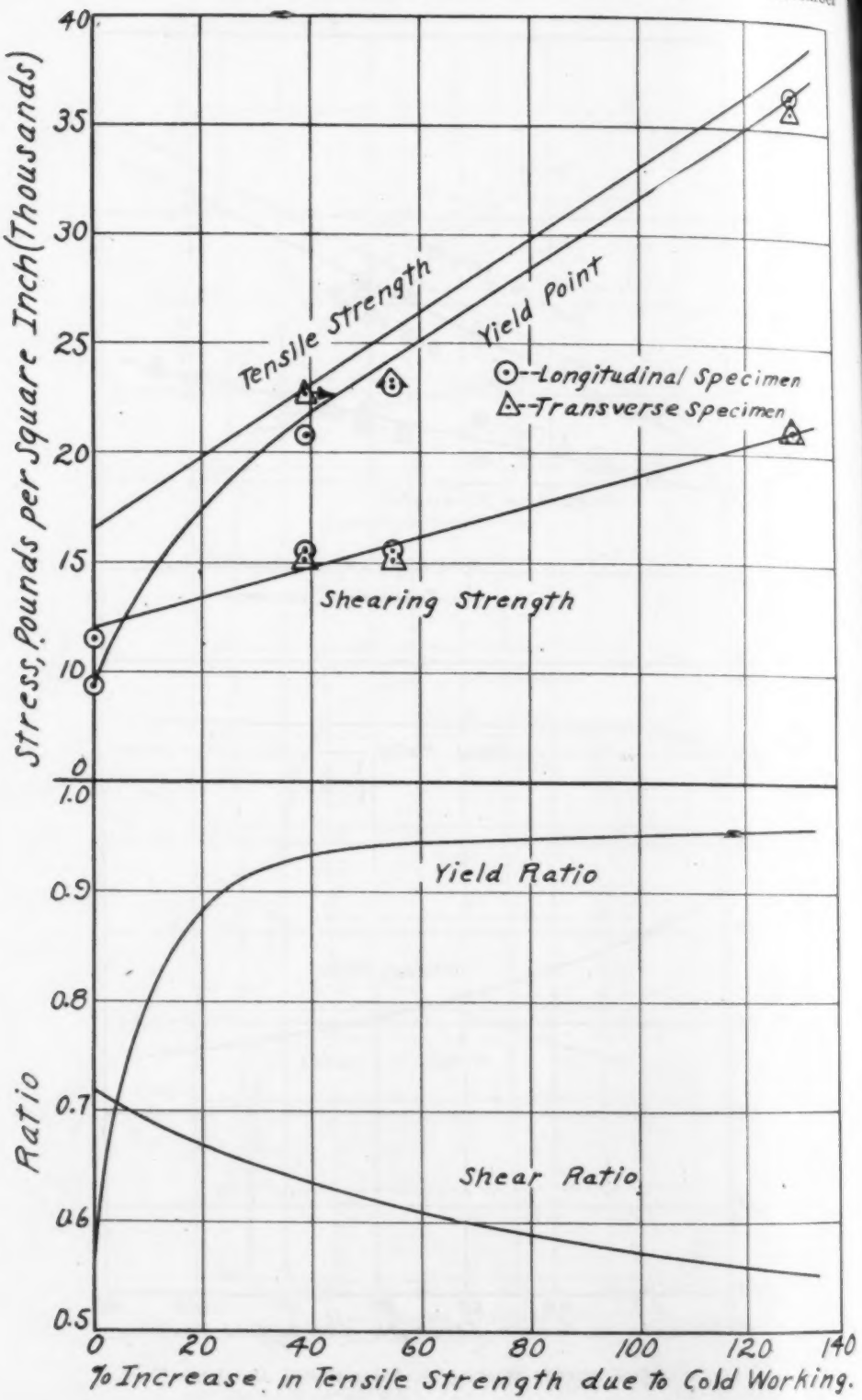

Fig. 7—Effect of Cold Working on Properties of Aluminum Manganese Alloy Sheet, Material DH.

Figs. 8 and 9 show results obtained with alpha brass sheet. As shown in Fig. 8, the curves for 69:31 brass differ in form from those shown in Figs. 3 to 7 inclusive. The curve of yield points in Fig. 8 rises less rapidly, and the curve of yield ratios approaches a maximum less abruptly than in the preceding figures. The line representing shearing strength, instead of being straight, is slightly curved; this makes the line representing shear ratios practically straight. As shown in Fig. 9, the curves for 66:34 brass are intermediate in form between the curves shown in Figs. 3 to 7 inclusive and those shown in Fig. 8. A line passing through the individual points for shearing strength would evidently be slightly curved.

To account for the abnormal form of the graphs for sheet brass the possibility of internal stress was investigated. The samples of sheet material shown in Figs. 1 to 14 inclusive were coated one side with paraffin, and the other side was subjected to acid attack. As the metal on one side of the sheet dissolved away the brass sheet specimens, especially those of 69:31 brass, curved decidedly. Specimens from other sheet material did not curve. It therefore seems possible that the abnormality of the curves in Figs. 8 to 9 is due to internal stress.

Figs. 10 to 14 inclusive show effect of cold working on tensile and shear properties of bar material. In Fig. 10 the values for individual yield point determinations have not been indicated. The curves for endurance limit in Figs. 10 and 11 will be discussed later. As shown in Figs. 10 to 14 inclusive, the curves for bar material are similar in form to the normal curves for sheet material shown in Figs. 3 to 7 inclusive. The shearing-strength relationship in each figure is expressed by a straight line. Since these figures represent ingot iron and a great variety of nonferrous material, it seems evident that when percentage increase in tensile strength due to cold working is used as abscissas, the effect of cold working on the tensile and shear properties of different metals does not differ greatly.

The shear ratio averages about 0.7 for annealed material and about 0.5 for severely cold-worked material.

In Figs. 3 to 14 inclusive shearing strength is plotted against percentage increase in tensile strength. It is of interest, however, to compare percentage increase in shearing strength with percentage increase in tensile strength due to cold working. In

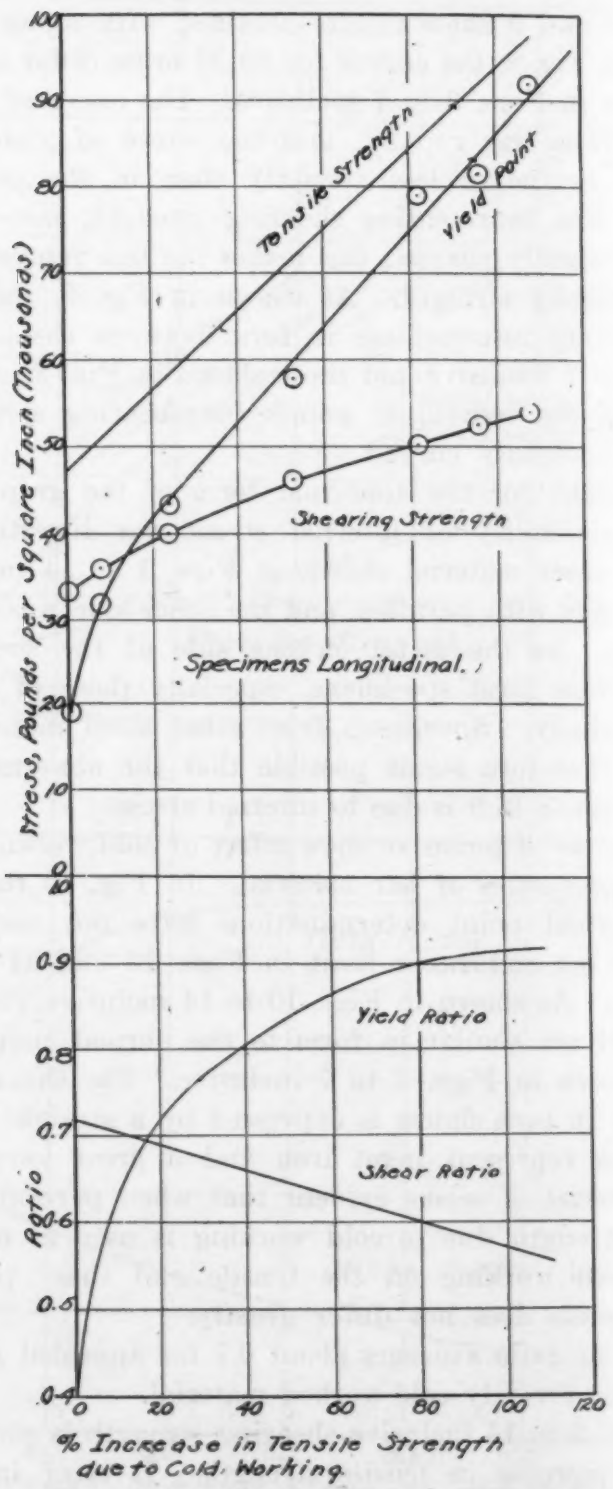

Fig. 8—Effect of Cold Working on Properties of 69:31 Brass Sheet, Material DO.

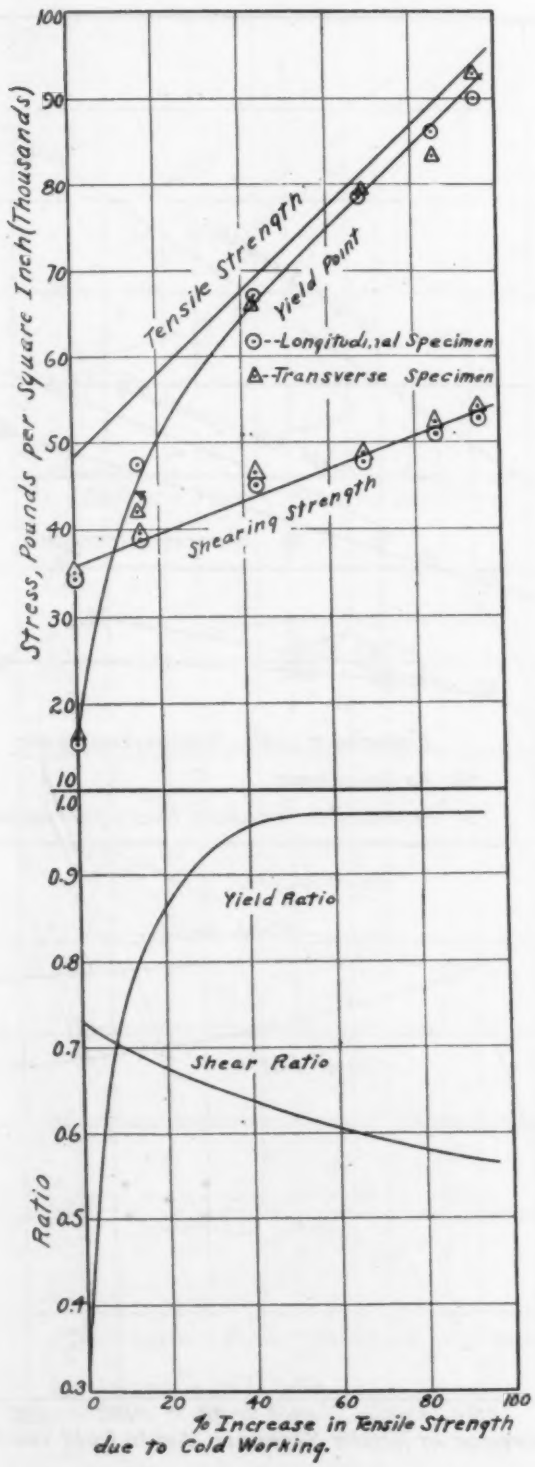

Fig. 9—Effect of Cold Working on Properties of 66:34 Brass Sheet, Material DF.

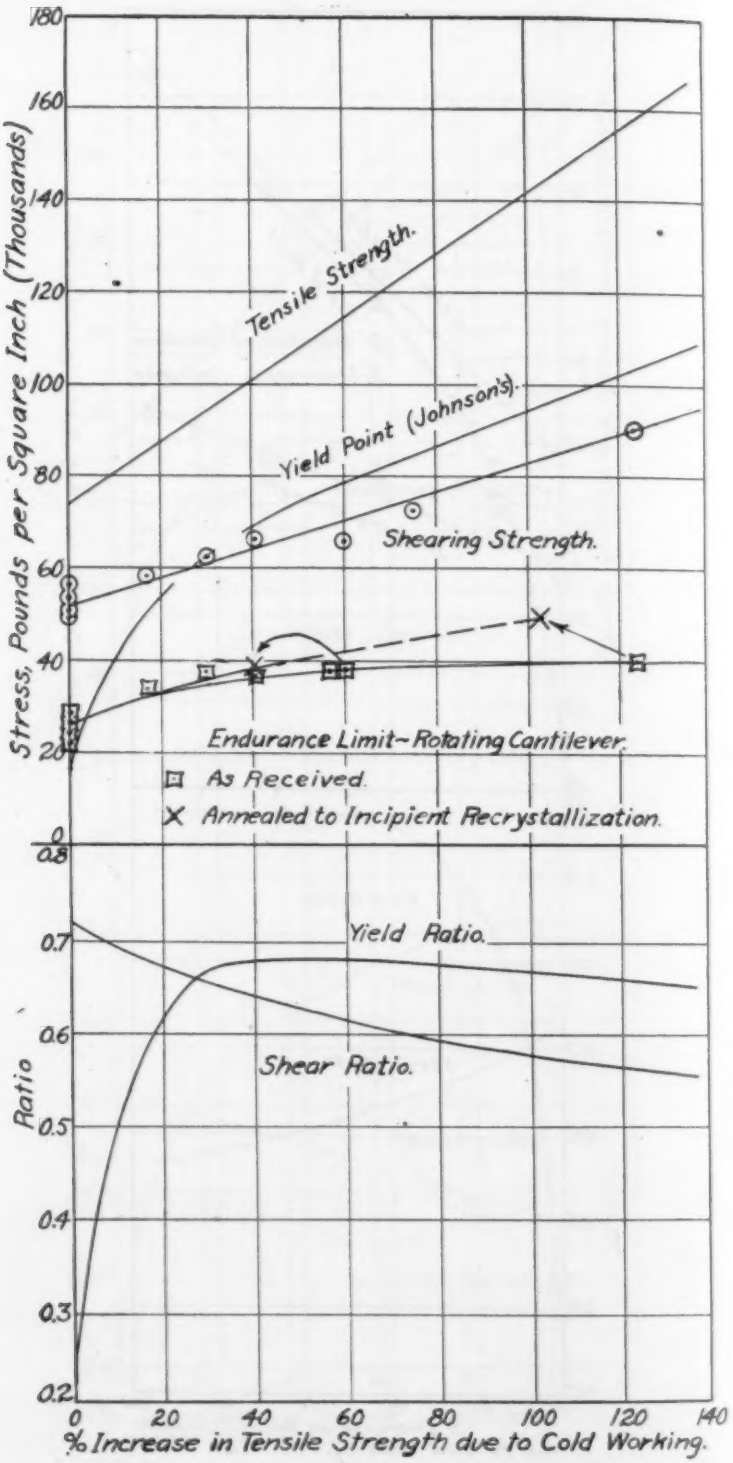

Fig. 10—Effect of Cold Working on Properties of Nickel Bars, Material A, CT and CR.

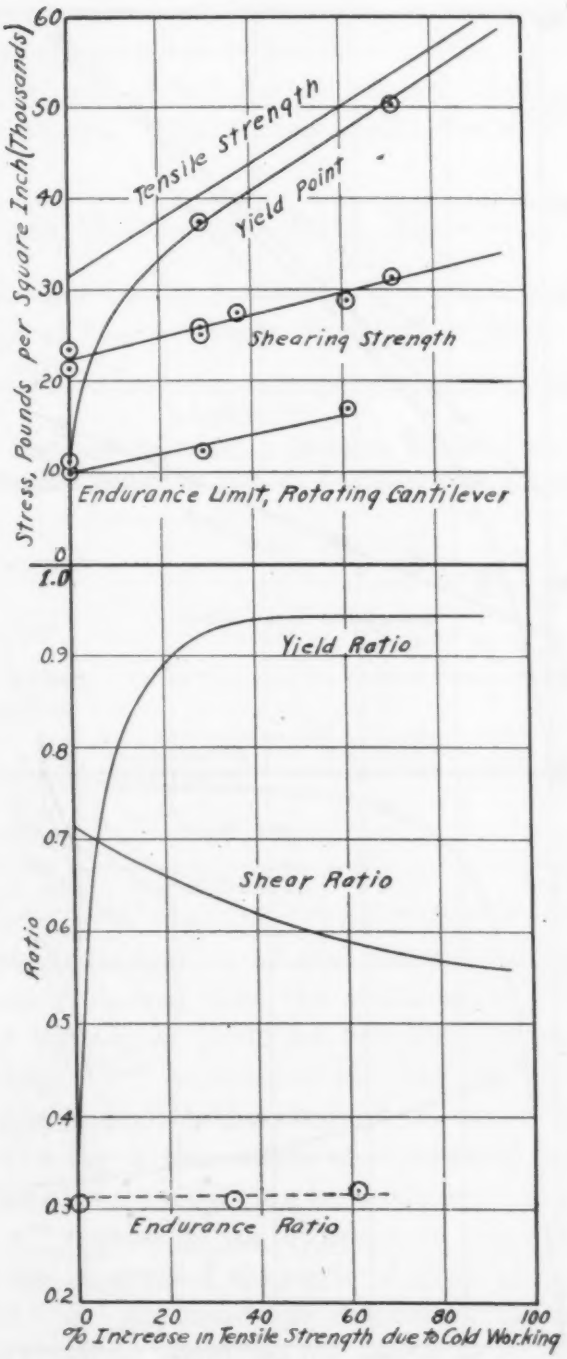

Fig. 11—Effect of Cold Working on Properties of Copper Bars, Materials BO, BU, CL and DI.

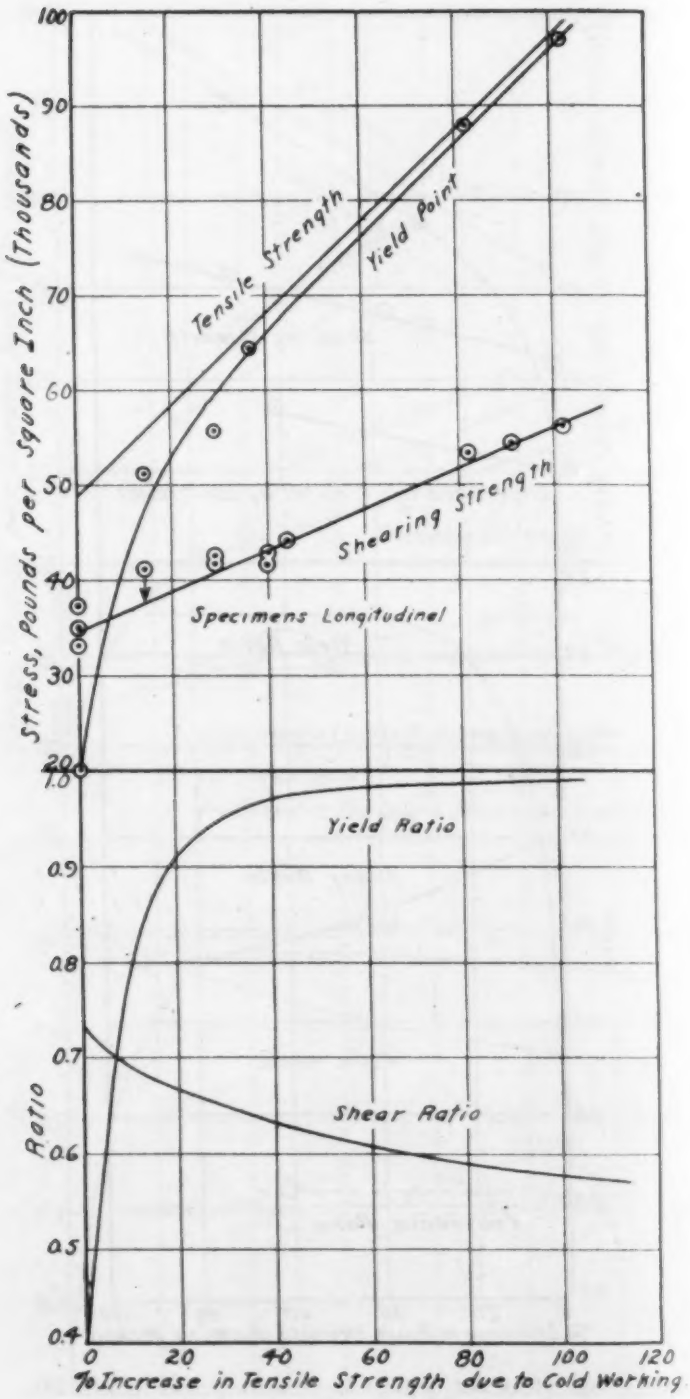

Fig. 12—Effect of Cold Working on Properties of 95:5 Bronze, Materials, CK, F and DG.

Table IV are listed ratios of percentage increase in shearing strength to percentage increase in tensile strength. As might be expected the ratios are higher for cylindrical shear specimens than for sheet material. The average ratio for sheet material is about 0.5.

Effect of Cold Working on Meyer Hardness Indices

About a year ago Dr. S. L. Hoyt, in a paper published in the Transactions of the American Society for Steel Treating,[8]

TABLE IV

Ratio of Per Cent Increase in Shearing Strength to Per Cent Increase in Tensile Strength Due to Cold-Working

Material	Material Designation	Ratio	
		Sheet Material	Bar Material
Ingot Iron, Cold-Rolled	DQ	...	0.50
Nickel, Cold-Rolled	DB, A, CT	0.43	0.62
Monel Metal, Cold-Rolled	DC	0.45	...
Constantan, Cold-Rolled	CV	...	0.50
Copper, Cold-Rolled	DJ, DI, CL	0.41	0.55
Alpha Copper-Tin Alloy, Cold-Drawn	CK, DG	...	0.63
Alpha Copper-Zinc Alloy, Cold-Drawn	CJ	...	0.60
69:31 Brass, Cold-Rolled	DO	0.60	...
66:34 Brass, Cold-Rolled	DF	0.51	...
Aluminum, Cold-Rolled	DE	0.54	...
Aluminum-Maganese Alloy, Cold-Rolled	DH	0.57	...

described Meyer's investigation of the ball-indentation hardness test. Meyer's work showed that the relationship between load and diameter of impression could be expressed by the equation $P = ad^n$, in which "P" represents the load on the indenting ball, and "d" represents the diameter of the impression. Since $\log P = \log a + n \log d$, the results of a series of measurements with different loads is expressed on a logarithmic scale as a straight line in which "a" represents the ordinate at unit diameter, and "n" represents the tangent of the angle of slope of the line. The indices "a" and "n" are constants depending on the material. "a" represents the load required for initial penetration and is closely related to the yield point, "n" represents the rate at which the metal hardens with cold working.

Since Hoyt points out that cold working causes "a" to in-

[8] S. L. Hoyt, "The Ball Indentation Hardness Test," Transactions American Society for Steel Treating, September, 1924.

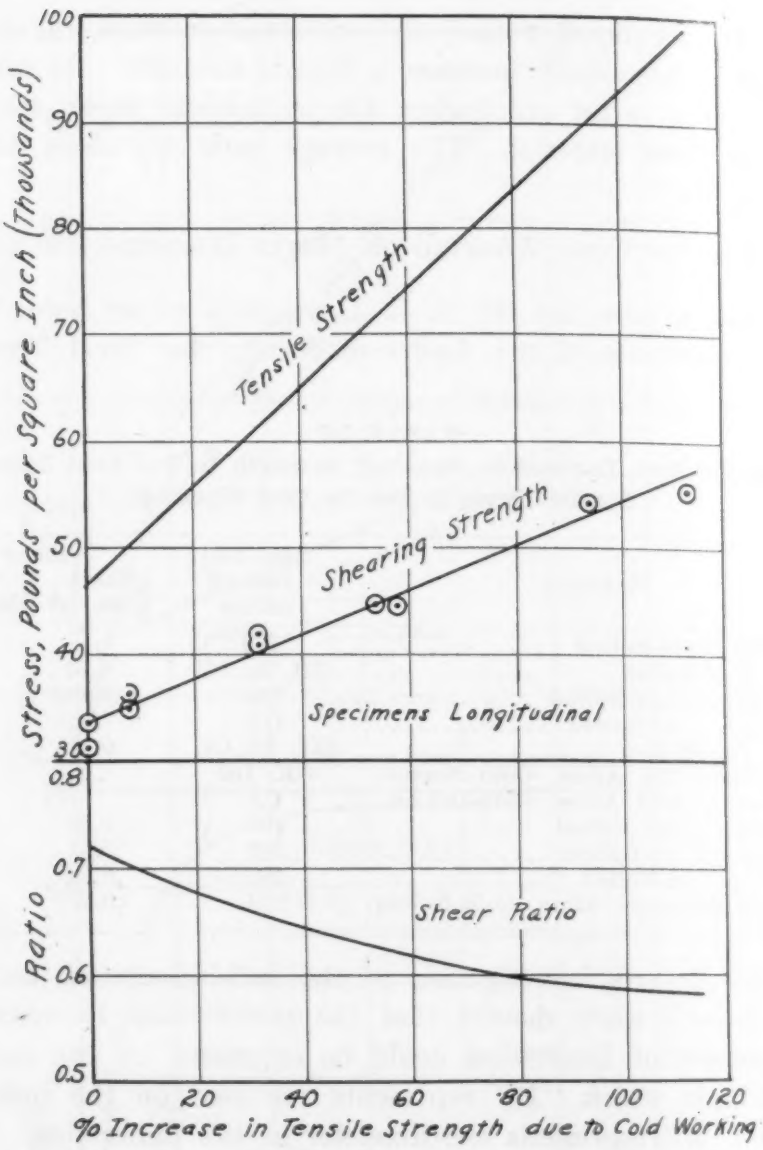

Fig. 13—Effect of Cold Working on Properties of 72:28 Brass Bars, Material CJ.

crease and "n" to decrease, it seemed desirable to investigate the effect of cold working on these two hardness indices. The Meyer hardness indices were, therefore, determined for a great variety of bar and sheet material. The results are illustrated by Figs. 15 to 18 inclusive.

Fig. 15 shows results obtained with severely cold-worked nickel and with an annealed sample of the same material. It will be noticed that the slope of the line representing annealed nickel

is greater than that of the line representing severely cold-worked nickel. At the origin, however, the ordinate of the former line is less than that of the latter. From a number of such curves, values for "a" and "n" have been obtained. Results thus obtained with three kinds of material are given in Figs. 16, 17 and 18.

Fig. 16 shows results obtained with nickel that had received various degree of cold working. As shown in this figure, the values for "n" decreases from about 2.5 to about 2.05 with increase in tensile strength due to cold working. The value for "a" increases with degree of cold working and apparently approaches a maximum. Figs. 17 and 18 show results obtained with copper and aluminum respectively. The curves are similar to those for nickel. In Figs. 17 and 18 the curves for "n" approach a minimum at a smaller percentage increase of tensile strength than does the "n" curve in Fig. 16. It is doubtful, however, whether the ball indentation test is sensitive enough to justify accurate comparison of the form of the "n" curve for different kinds of material. Apparently the "n" curve approaches a horizontal direction more abruptly than does the curve of shear ratios, as shown in Figs. 3 to 14 inclusive. The "n" curve for nickel, as shown in Fig. 1, if inverted, would be somewhat similar in form to the curve of rotating-cantilever endurance limits, as shown in Fig. 9 of a previous paper. Further investigation of the endurance properties of severely cold-worked material must be made, however, before definite comparison can be drawn between curves of endurance limits and any of the curves shown in Figs. 3 to 18 inclusive.

Effect of Cold Working on Endurance Properties of Copper

In previous papers[3, 6] the endurance properties of cold-worked copper were discussed. No direct comparison was made, however, between the rotating-cantilever endurance limits of cold-worked and of fully annealed copper. Fig. 19 shows results obtained with rather severely cold-worked copper and with the same material after complete annealing. As shown in this figure, the curve for cold-worked copper is approaching a horizontal direction between 50,000,000 and 100,000,000 cycles. The curve for fully annealed copper becomes practically horizontal at less than 50,000,000 cycles. The endurance limits of the cold-rolled and

[6] D. J. McAdam Jr. "Endurance Properties of Metals," *Mechanical Engineering*, July 1925.

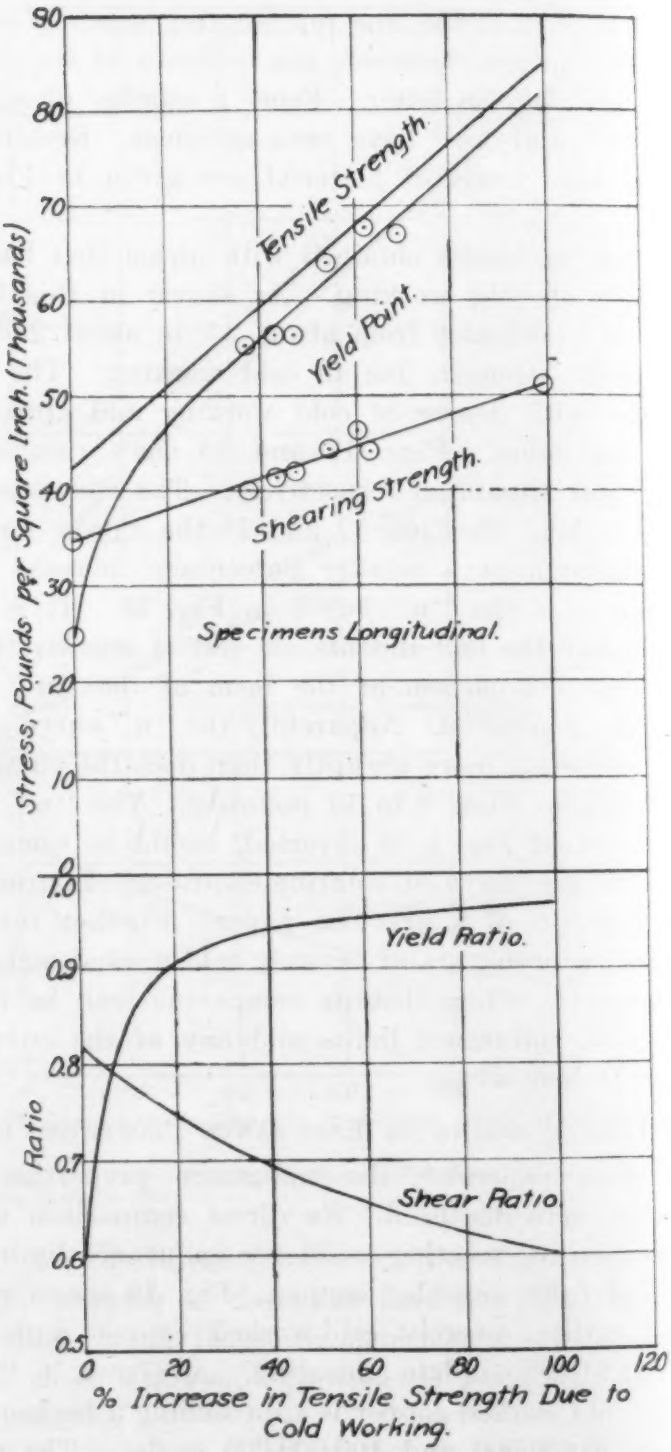

Fig. 14—Effect of Cold Working on Properties of Ingot Iron Bars, Materials DT, N-5 and DQ.

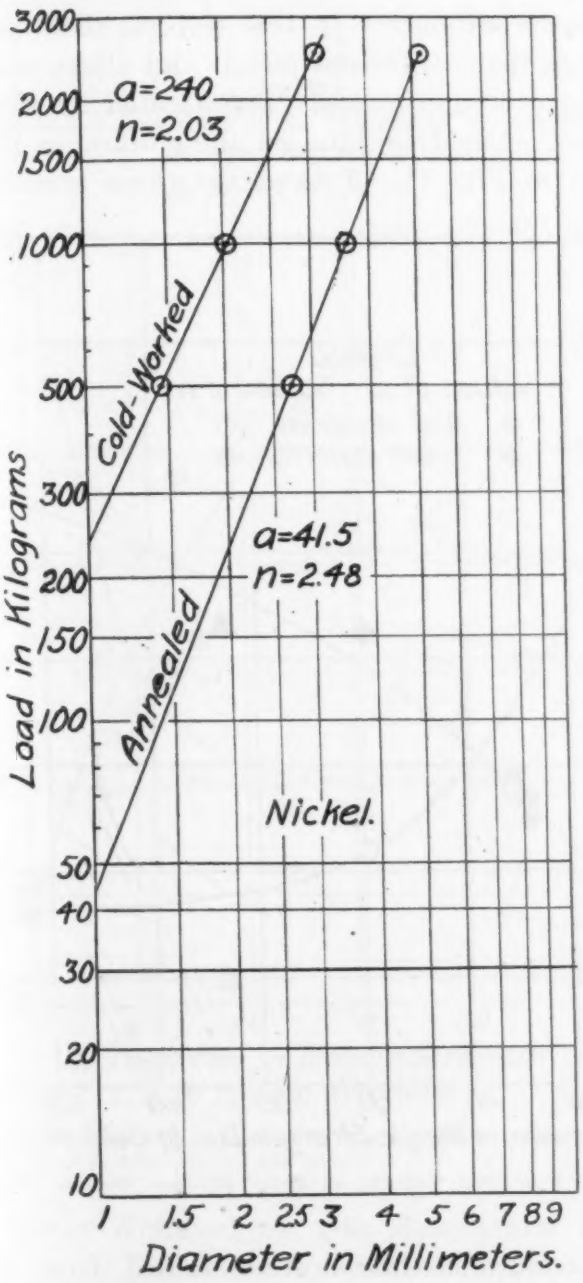

Fig. 15—Ball Indentation Hardness Test. Relation Between Load and Diameter of Impression. Nickel Bars.

of the fully annealed material are evidently about 16,000 and 10,000 pounds per square inch respectively. The tensile strength of the cold-worked material had been increased by cold working about 62 per cent above that of fully annealed material. The endurance limit has been increased about in proportion to the in-

crease in tensile strength. In this respect, therefore, copper behaves like the other nonferrous metals and alloys whose endurance properties have been previously investigated by the writer.

The effect of cold working on the endurance limit of copper is illustrated in Fig. 11. Two of the three experimental points

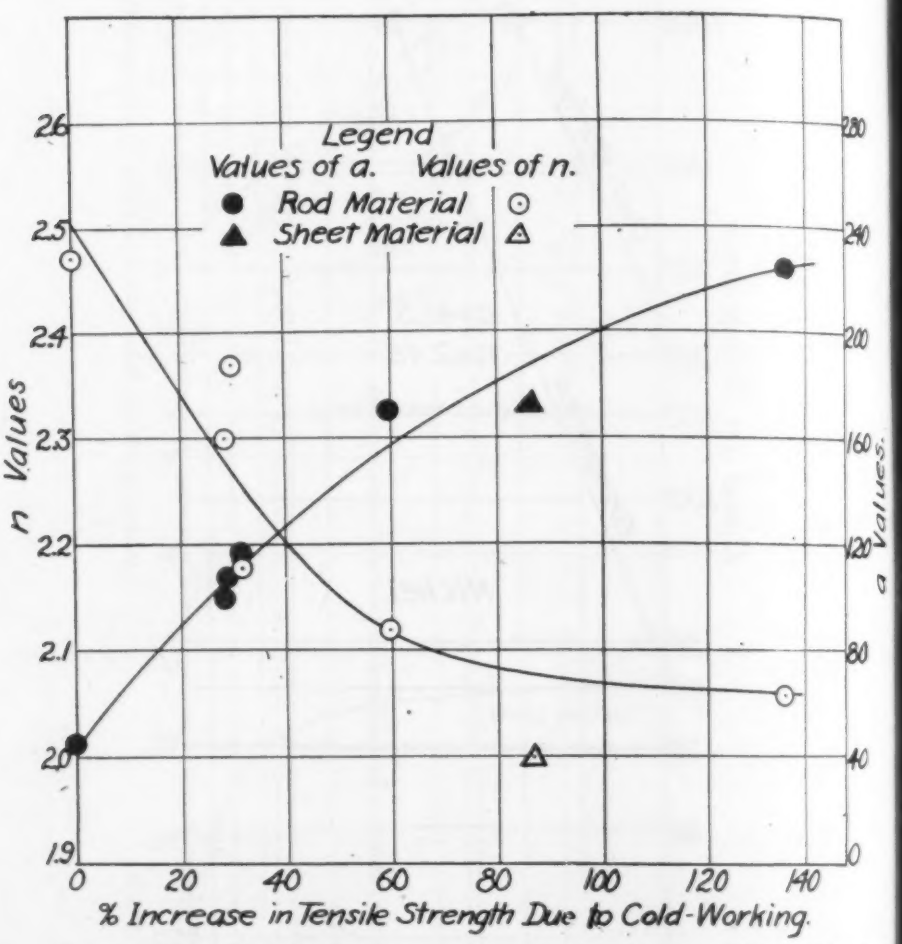

Fig. 16—Effect of Cold Working on Meyer Hardness Indices, Nickel, Materials A and DB.

representing endurance limits are obtained from Fig. 19; the third point was obtained from a previous paper.[6] A comparison of the line of endurance limits in Fig. 11 with the solid line of endurance limits for nickel in Fig. 10 shows that the former at an abscissa of 60 has not begun to curve toward a horizontal direction as has the latter. The broken line of endurance limits in Fig. 11 represents the approximate effect of cold working followed by anneal at about the temperature of incipient crystallization.

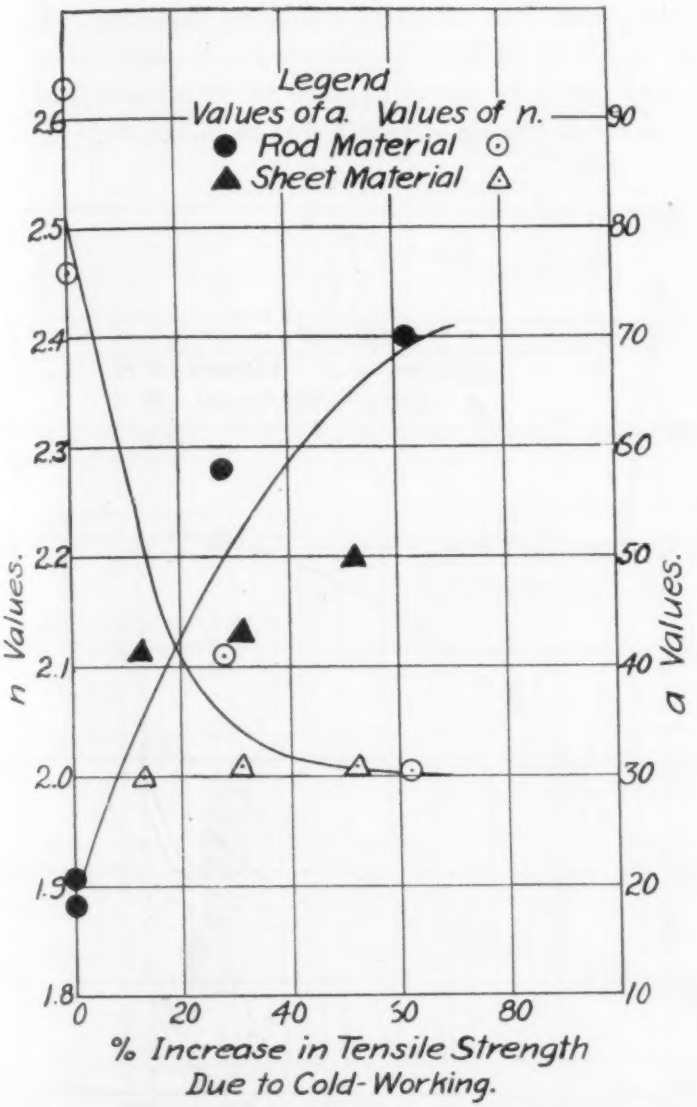

Fig. 17—Effect of cold working on Meyer Hardness Indices Copper, Materials BO, BU, CL, DI and DJ.

Effect of Cold Working on the Endurance Properties of Copper-Tin Alloys

Fig. 20 shows rotating-cantilever results obtained with copper-tin alloys. The upper and lower curves represent alloys containing about 10 per cent and 5 per cent tin respectively. The small circles represent cold-worked material, and the triangles represent fully annealed material. It will be noticed that for each of these alloys the endurance limit of the cold-worked material

is no higher than that of fully annealed material. In an investigation of a great variety of alloys these copper-tin alloys were the first that failed to show increase of endurance limit in proportion to increase in tensile strength due to moderate cold working. It

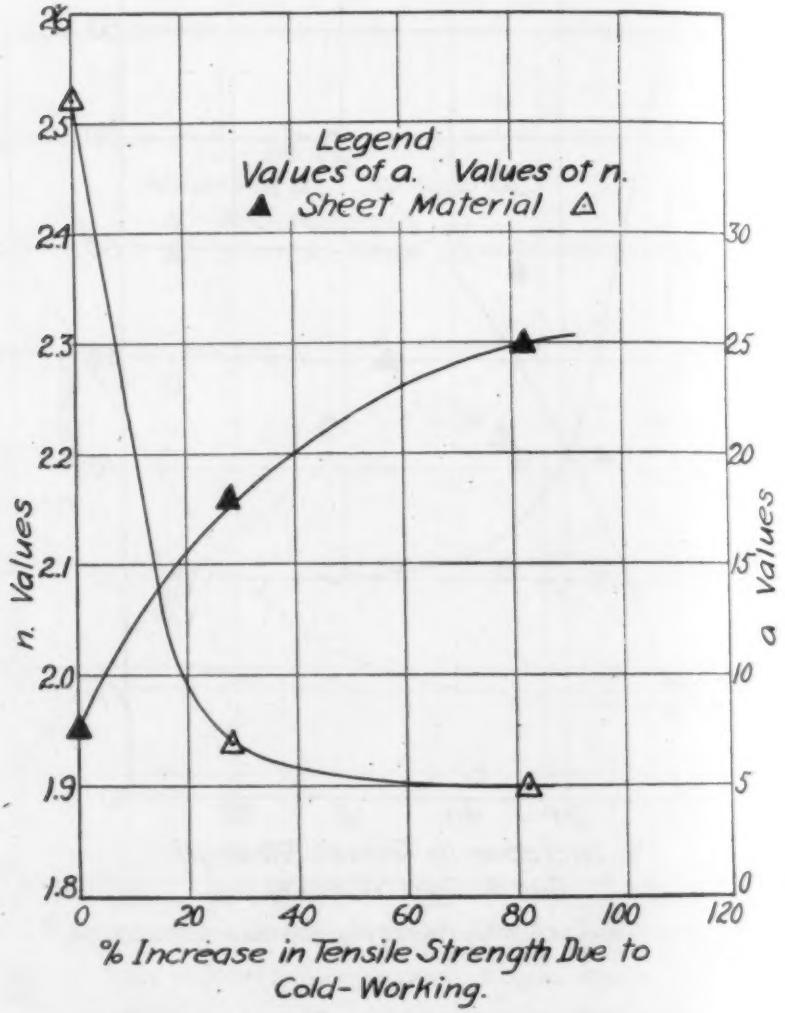

Fig. 18—Effect of Cold Working on Meyer Hardness Indices, Aluminum, Material DE.

seemed possible that this abnormality might be due to inclusion or small flaws, since such defects might be expected to lower th endurance limit of work-hardened more than that of anneale material. Investigation of brass alloys now to be described, how ever, disclosed another possible cause of the abnormal behavio of the copper-tin alloys.

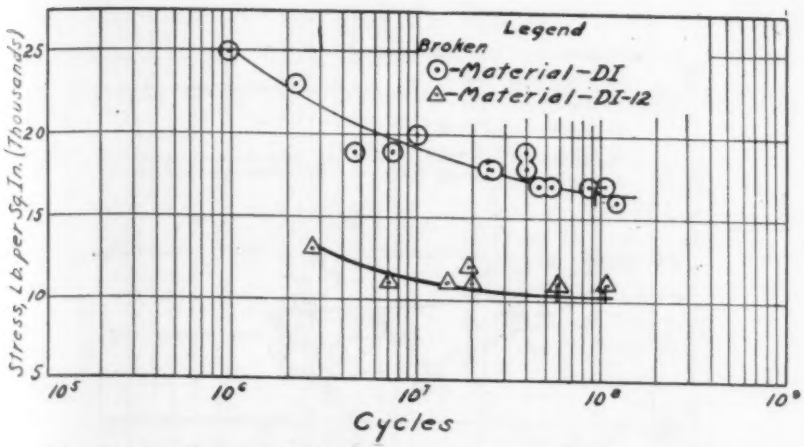

Fig. 19—Results of Rotating Cantilever Endurance Tests, Copper, Materials DI and DI-12.

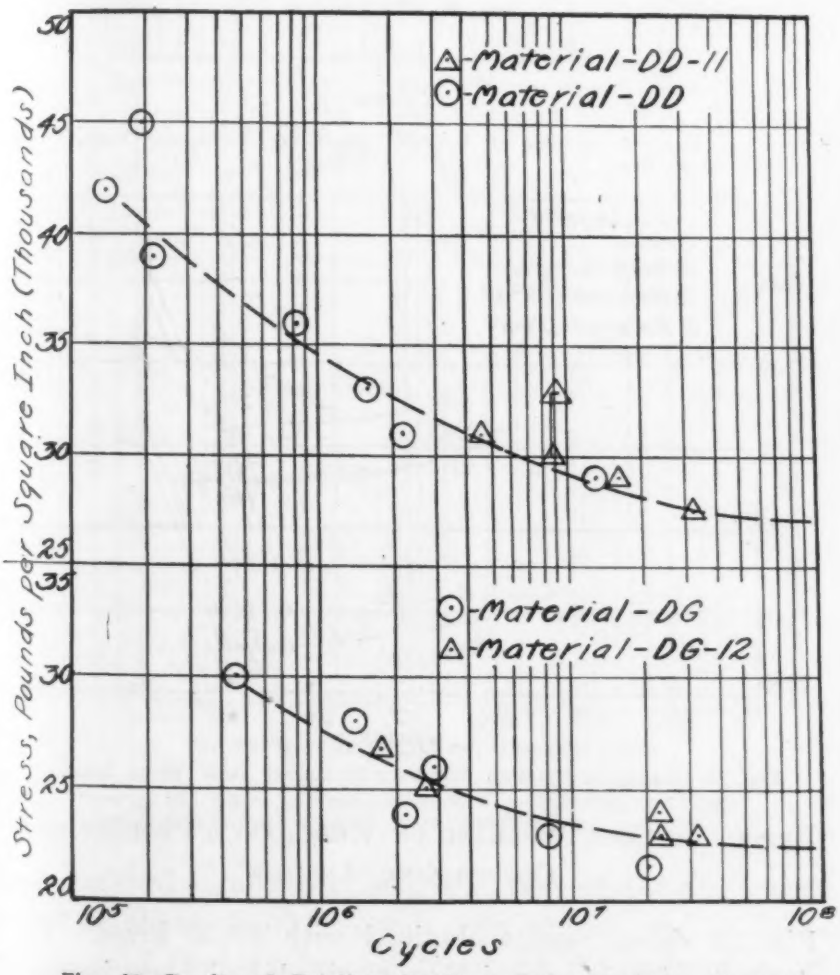

Fig. 20—Results of Rotating Cantilever Endurance Tests, Copper-Tin Alloys.

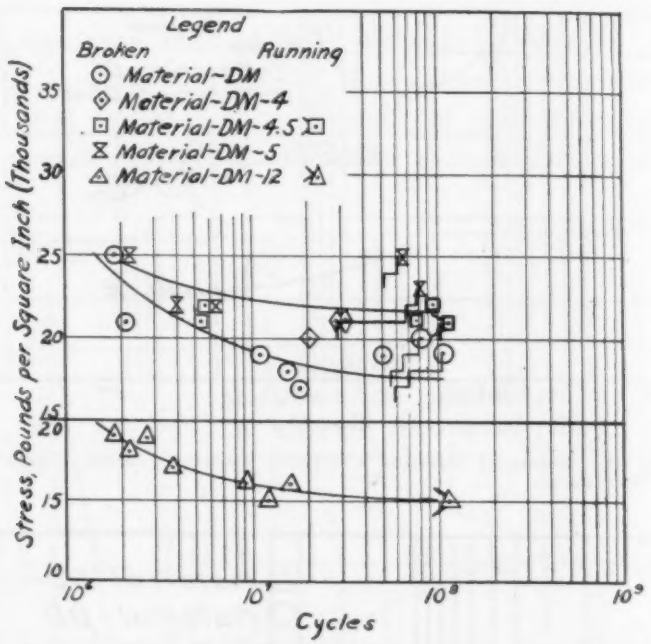

Fig. 21—Results of Rotating Cantilever Endurance Tests, 70:30 Brass.

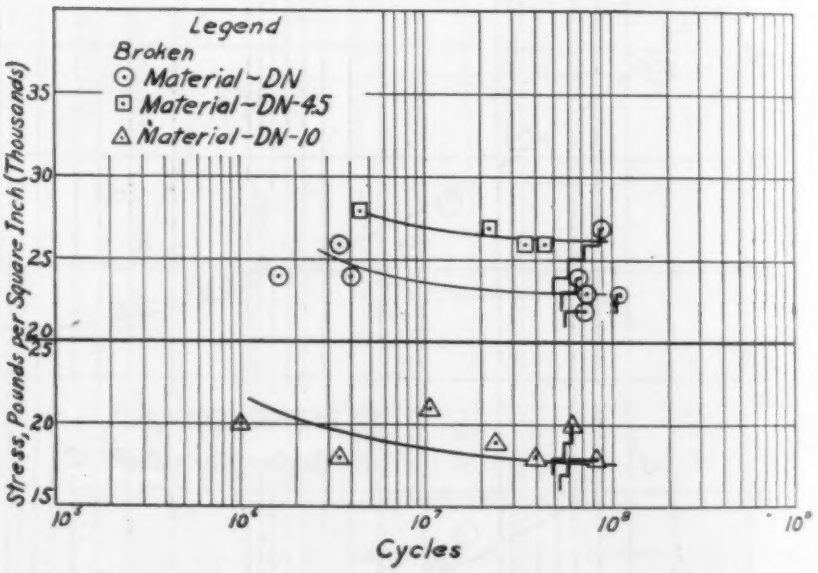

Fig. 22—Results of Rotating Cantilever Endurance Tests, 80:30 Brass.

Effect of Cold Working on Endurance Properties of Copper-Zinc Alloys

Fig. 21 shows results obtained with 70:30 brass. The tensile strength of this material as received had been increased by cold working about 63 per cent above that of fully annealed

material. The next lowest and the lowest curves in this figure show results obtained with material as received and with fully annealed material respectively. The endurance limit of the cold-

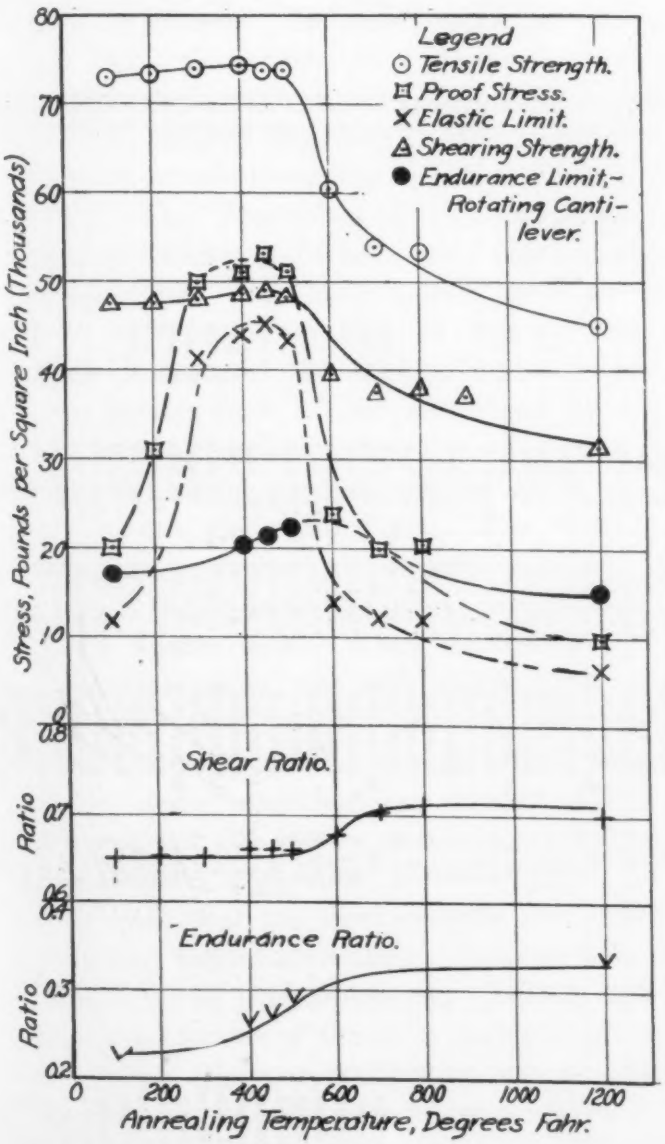

Fig. 23—Effect of Temperature of Anneal on Physical Properties of Cold-Worked 70:30 Brass, Material DM.

worked material is about 17,500, and that of the fully annealed material is about 15,000 pounds per square inch. Evidently, therefore, cold working has not increased the endurance limit of this alloy in proportion to the increase in tensile strength. In

Table V

Relationship of Other Physical Properties to Tensile Strength—Bar Material

Material	Material Designation	Condition	Average Tensile Strength, Lb. Per Sq. In.	Average Shearing Strength, Lb. Per Sq. In.	Endurance Limit, Lb. Per Sq. In. Rotating Cantilever	Endurance Limit, Lb. Per Sq. In. Torsion Alternating	Shear Ratio Col. 5 to Col. 4	Endurance Ratio Col. 6 to Col. 4	Endurance Ratio Col. 7 to Col. 4
Ingot Iron, Rolled	DQ	As Received	*62,400	*41,900	.....	.....	0.67	...	...
Ingot Iron, Rolled	DQa	As Received	*60,900	41,200	.....	.....	0.68	...	...
Ingot Iron, Rolled	DQb	As Received	*58,200	40,000	.....	.....	0.69	...	...
Ingot Iron, Rolled	BT	Annealed	*42,500	34,800	.....	.....	0.82	...	...
Nickel, Cold-Rolled	A-5.5	Annealed	165,500	94,900	.....	20,000	0.57	...	0.12
Nickel, Cold-Rolled	A-11.0	Annealed	**142,600	83,700	.....	28,500	0.59	...	0.20
Nickel, Cold-Rolled	A-16.0	Annealed	70,400	50,400	.....	22,000	0.72	...	0.30
Nickel, Cold-Rolled	CT	As Received	†115,800	65,500	.....	20,500	0.57	...	0.18
Nickel, Cold-Rolled	CT-5.5	Annealed	**113,900	70,900	.....	20,500	0.62	...	0.18
Nickel, Cold-Rolled	CT-10	Annealed	*101,500	67,600	.....	24,500	0.67	...	0.24
Nickel, Cold-Rolled	CT-16	Annealed	††72,400	51,900	.....	22,000	0.72	...	0.30
Copper, Cold-Rolled	D-I	As Received	52,000	*28,400	16,000	.....	0.55	0.30	...
Copper, Cold-Rolled	DI-3	Annealed	*53,300	*28,400	.....	.....	0.53	...	...
Copper, Cold-Rolled	DI-4	Annealed	*51,000	*28,100	.....	.....	0.55	...	...
Copper, Cold-Rolled	DI-5	Annealed	*34,700	*23,900	.....	.....	0.69	...	...
Copper, Cold-Rolled	DI-6	Annealed	*33,900	*23,000	.....	.....	0.68	...	...
Copper, Cold-Rolled	DI-8	Annealed	*33,100	*22,900	.....	.....	0.69	...	...
Copper, Cold-Rolled	DI-12	Annealed	32,100	22,500	10,500	.....	0.70	0.33	...
95:5 Bronze, Cold-Rolled	DG	As Received	55,800	41,700	22,500	.....	0.75	0.40	...
95:5 Bronze, Cold-Rolled	DG-4	Annealed	*56,100	*42,000	.....	.....	0.75	...	...
95:5 Bronze, Cold-Rolled	DG-5	Annealed	*55,000	*40,500	.....	.....	0.74	...	...
95:5 Bronze, Cold-Rolled	DG-6	Annealed	*54,000	*39,500	.....	.....	0.73	...	...
95:5 Bronze, Cold-Rolled	DG-7	Annealed	*54,300	*39,000	.....	.....	0.72	...	...
95:5 Bronze, Cold-Rolled	DG-9	Annealed	*51,800	*37,700	.....	.....	0.73	...	...
95:5 Bronze, Cold-Rolled	DG-10.5	Annealed	*48,500	*35,800	.....	.....	0.74	...	...
95:5 Bronze, Cold-Rolled	DG-12	Annealed	48,100	36,100	22,500	.....	0.75	0.47	...
89:11 Bronze, Cold-Rolled	DD	As Received	82,800	60,500	27,000	.....	0.73	0.33	...
89:11 Bronze, Cold-Rolled	DD-11	Annealed	67,600	29,000	27,000	.....	0.43	0.40	...
81:19 Brass, Cold-Drawn	DN	As Received	76,500	48,200	23,000	.....	0.63	0.29	...
81:19 Brass, Cold-Drawn	DN-3	Annealed	*77,500	*48,900	.....	.....	0.63	...	...
81:19 Brass, Cold-Drawn	DN-4.5	Annealed	*80,500	*49,700	26,000	.....	0.62	0.32	...
81:19 Brass, Cold-Drawn	DN-6	Annealed	*50,000	*36,200	.....	.....	0.72	...	...
81:19 Brass, Cold-Drawn	DN-7	Annealed	*49,000	*34,900	.....	.....	0.71	...	...
81:19 Brass, Cold-Drawn	DN-8	Annealed	*48,500	*34,900	.....	.....	0.72	...	...
81:19 Brass, Cold-Drawn	DN-9	Annealed	*45,800	*33,100	.....	.....	0.72	...	...
81:19 Brass, Cold-Drawn	DN-10	Annealed	44,000	31,700	17,500	.....	0.72	0.40	...
81:19 Brass, Cold-Drawn	DN-12	Annealed	*43,200	*31,600	.....	.....	0.73	...	...
70:30 Brass, Cold-Rolled	DM	As Received	**73,200	47,700	17,500	.....	0.65	0.24	...
70:30 Brass, Cold-Rolled	DM-2	Annealed	*73,300	*47,400	.....	.....	0.65	...	...
70:30 Brass, Cold-Rolled	DM-3	Annealed	*74,000	*48,200	.....	.....	0.65	...	...
70:30 Brass, Cold-Rolled	DM-4	Annealed	*73,000	*48,700	20,000	.....	0.66	0.27	...
70:30 Brass, Cold-Rolled	DM-4.5	Annealed	*73,800	*29,000	20,000	.....	0.66	0.27	...
70:30 Brass, Cold-Rolled	DM-5	Annealed	**73,400	48,400	21,500	.....	0.66	0.29	...
70:30 Brass, Cold-Rolled	DM-6	Annealed	*60,500	*39,600	.....	.....	0.65	...	...
70:30 Brass, Cold-Rolled	DM-7	Annealed	*54,000	*37,800	.....	.....	0.70	...	...
70:30 Brass, Cold-Rolled	DM-8	Annealed	*55,100	*37,900	.....	.....	0.71	...	...
70:30 Brass, Cold-Rolled	DM-9	Annealed	*54,800	*37,800	.....	.....	0.68	...	...
70:30 Brass, Cold-Rolled	DM-12	Annealed	46,000	31,400	15,000	.....	0.70	0.33	...

this respect the alloy behaves like the copper-tin alloys illustrated in Fig. 20.

It seems possible that the abnormal endurance properties of the copper-tin and copper-zinc alloys might be due to internal stress in the test specimens. In machining the test specimens from the original bar a thick outer layer is removed, thus relieving part of any internal stress that may have been in the original bar. Nevertheless, it seemed desirable to investigate these alloys to determine whether or not there was considerable internal stress in the finished specimen. Specimens of various metals and alloys used in these and preceding endurance tests are, therefore, being tested for internal stress. The investigation thus far has shown that the material represented in Fig. 21 had an initial tensile stress (in the outer layers of the original 1-inch bar), of about 50,000 pounds per square inch. After machining the outer layers to a diameter of about ½ inch (the diameter of the test specimen), the outer layer at this diameter still had an initial tensile stress of about 25,000 pounds per square inch. The 89:11 copper-tin alloy, whose endurance properties are illustrated in Fig. 10, showed in the outer layer of the ¾-inch bar initial tensile stress of about 18,000 pounds per square inch. When machined to a diameter of ½ inch the initial stress was still about 8,000 pounds per square inch. No more of the 95:5 copper-tin alloy was available for internal stress tests, but another sample of the same composition and from the same manufacturer showed initial stress of 30,000 at a diameter of 0.9 inches and about 7,000 after being machined to a diameter of ½ inch.

It seemed possible that the unexpectedly low endurance limits of the cold-worked copper-zinc alloy (material DM, illustrated in Fig. 21), were due to internal stress. Additional endurance tests were made on specimens of the same material after annealing at temperatures below the recrystallization range. This annealing was for the purpose of relieving internal stress, but without effecting an important decrease in tensile strength. As shown by experimental points in Fig. 21, annealing for an hour at 400 degrees Fahr. has evidently raised the endurance limit considerably. Annealing at 450 and 500 degrees Fahr., however, raises the endurance limit still higher, as indicated by the upper curve in Fig. 21. As shown in this figure, the results obtained by these low temperature annealings were somewhat irregular. The ir-

regularity in the results may possibly be due in part to slight temperature variation in a furnace which was not well adapted for use at these comparatively low temperatures. With more careful temperature regulation and longer time of annealing, even more improvement in endurance properties may be possible. As shown in Fig. 21, the average endurance limit of the material annealed at 500 degrees Fahr. is nearly 50 per cent greater than that of fully annealed material. Apparently the upper curve is less steep than that of the material as received; it is similar in form to the lowest curve, which represents fully annealed material.

Fig. 22 shows results obtained with 81:19 brass. The tensile strength of this material as received had been increased by cold working about 77 per cent above that of fully annealed material. The middle and lowest curves in this figure show results obtained with material as received and with fully annealed material respectively. The endurance limit of the material as received is about 23,000 pounds per square inch, and that of fully annealed material is about 17,500 pounds per square inch. The increase in endurance limit (about 30 per cent) by cold working is evidently not in proportion to the increase in tensile strength.

Specimens of the same material were, therefore, annealed for an hour at 450 degrees Fahr. in order to relieve possible internal stress without important decrease in tensile strength. The effect on the endurance properties is shown in the upper curve of Fig. 22, which represents material annealed at 450 degrees Fahr. After this annealing the endurance limit is about 45 per cent higher than that of fully annealed material. It is possible that further improvement could be produced by increasing either the temperature or the time of the low temperature annealing.

Evidently, however, even after low temperature annealing the endurance limit of these specimens of rather severely cold-worked brass would not be increased in proportion to the increase in tensile strength. Possibly for this material, as for nickel[5], the increase in endurance limit with cold working ceases to be proportional to the increase in tensile strength when the percentage increase of tensile strength by cold working exceeds a maximum value. For nickel this maximum percentage is about 50; for copper and constantan it is not less than 50. For alpha solid solutions of tin or zinc in copper, this maximum percentage possibly decreases as the proportion of tin or zinc approaches the satura-

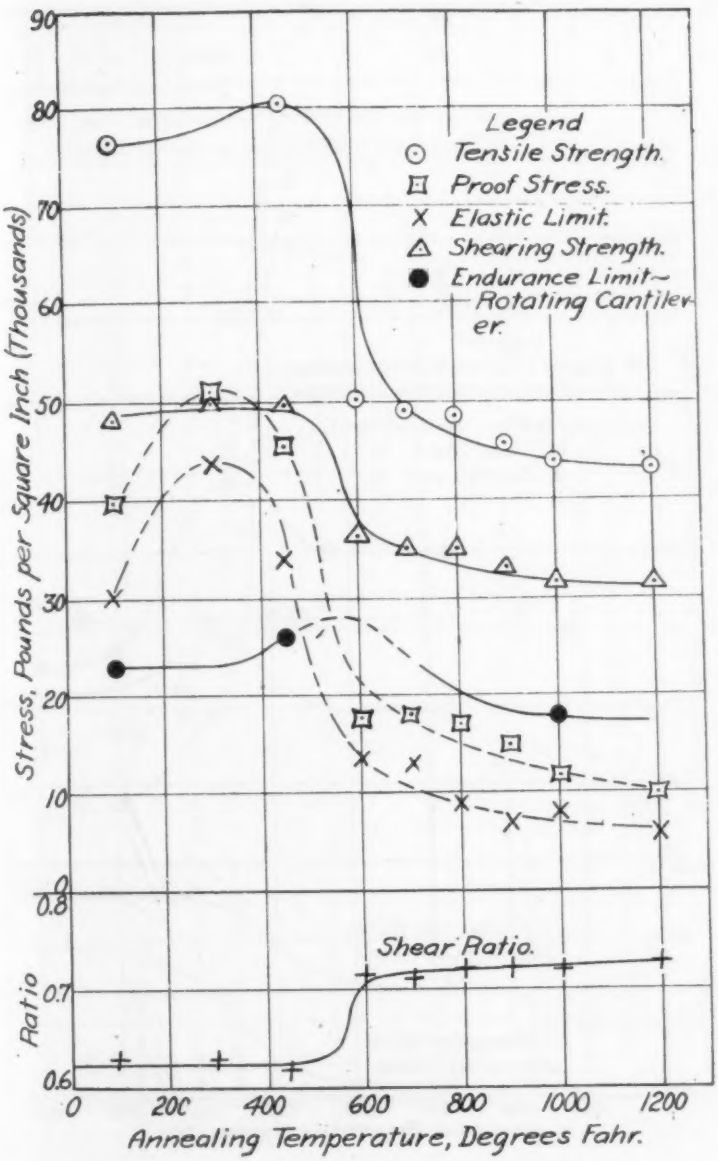

Fig. 24—Effect of Temperature of Anneal on Physical Properties of Cold-Worked 80:20 Brass, Material DN.

tion value for the alpha solid solution. If so, increase in endurance limit of copper by addition of tin or zinc would be accomplished at the expense of possibility of effective increase of endurance limit by cold working. Additional investigation will be necessary to determine the interrelation between effect of chemical composition and degree of cold working on the endurance limits of copper-tin and copper-zinc alloys.

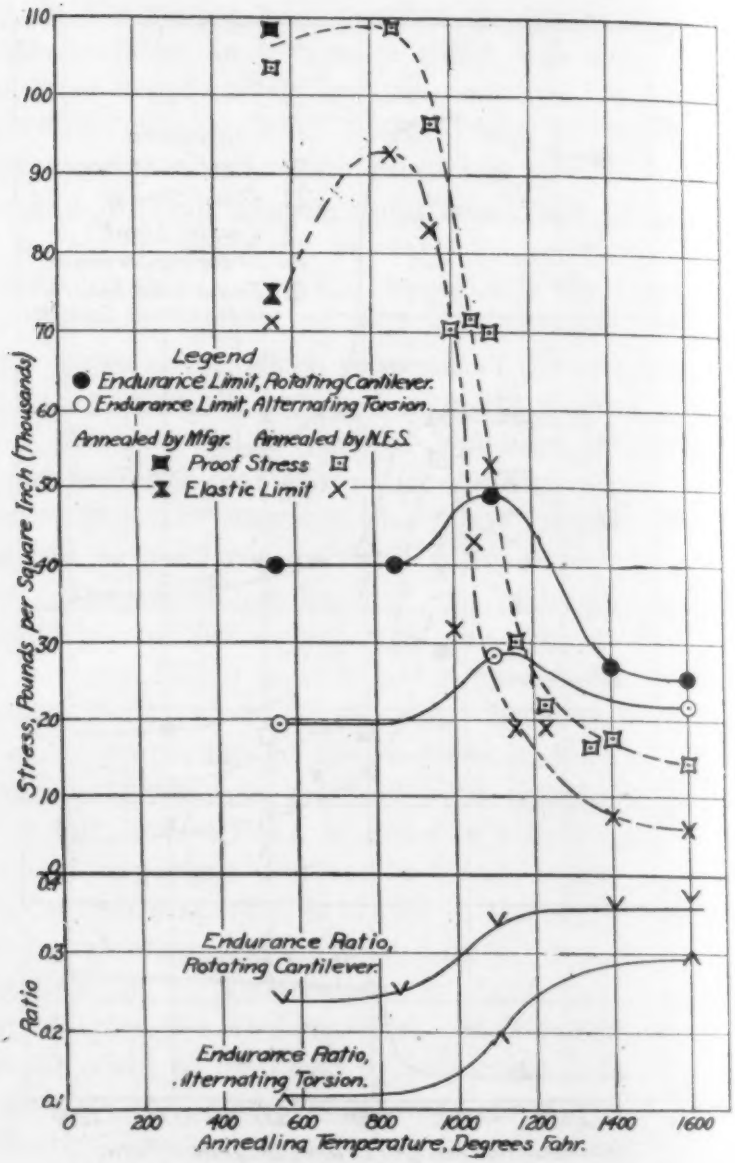

Fig. 25—Effect of Temperature of Anneal on Physical Properties of Cold-Worked Nickel, Material A.

Effect of Annealing Temperature on Endurance and Other Physical Properties of Copper-Zinc Alloys

Fig. 23 compares the effect of annealing temperature on the endurance limit of cold-worked 81:19 brass with the effect of annealing temperature on other physical properties. As shown in this figure, the proof stress and elastic limit increase rapidly with increase in annealing temperature up to 400-500 degrees Fahr.; above this temperature of annealing these physical properties de-

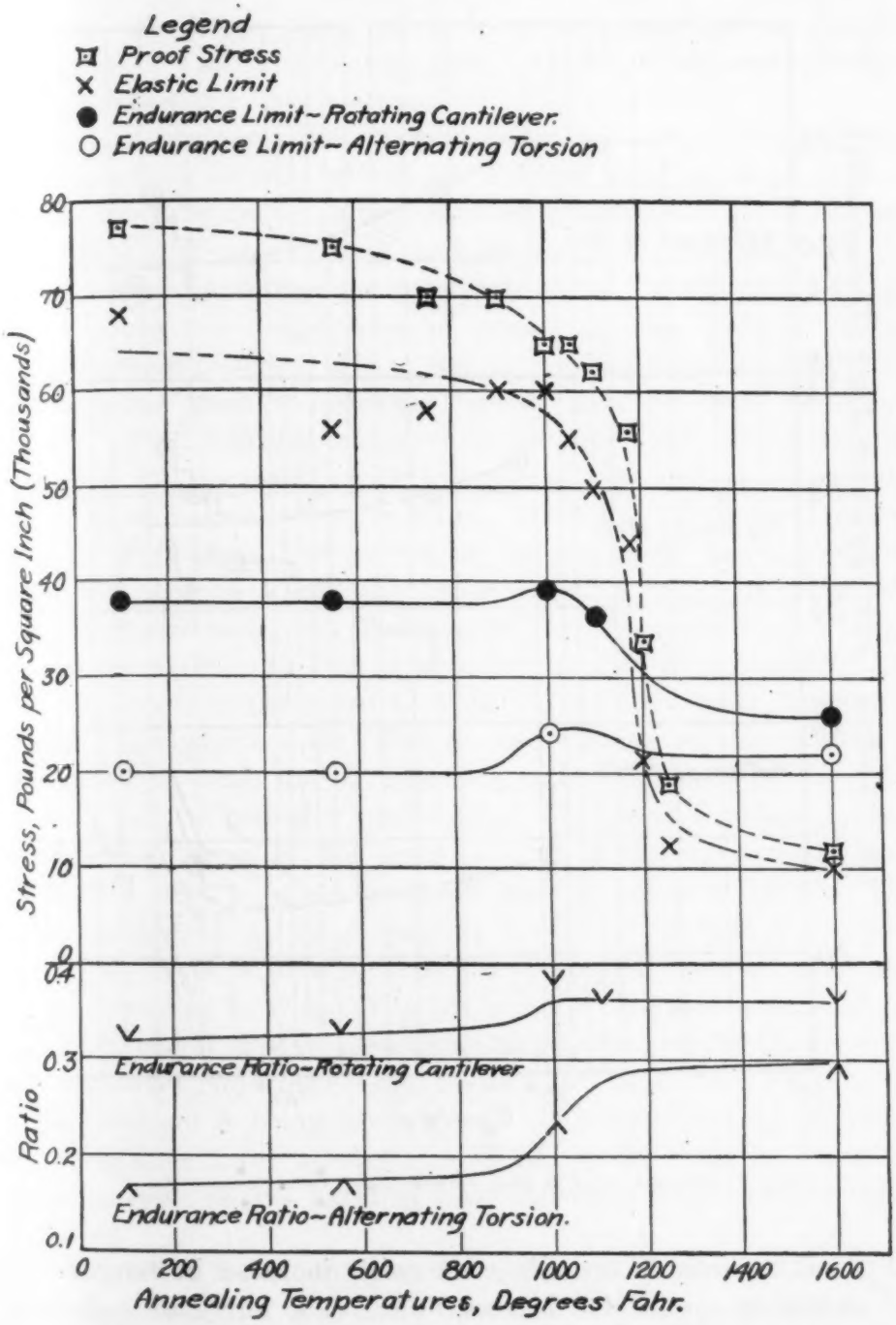

Fig. 26—Effect of Temperature of Anneal on Physical Properties of Cold-Worked Nickel, Material CT.

crease rapidly. Above 500 degrees Fahr., tensile strength and shearing strength decrease rapidly, and the shear ratio increases. The rotating-cantilever endurance limit (as obtained from Fig.

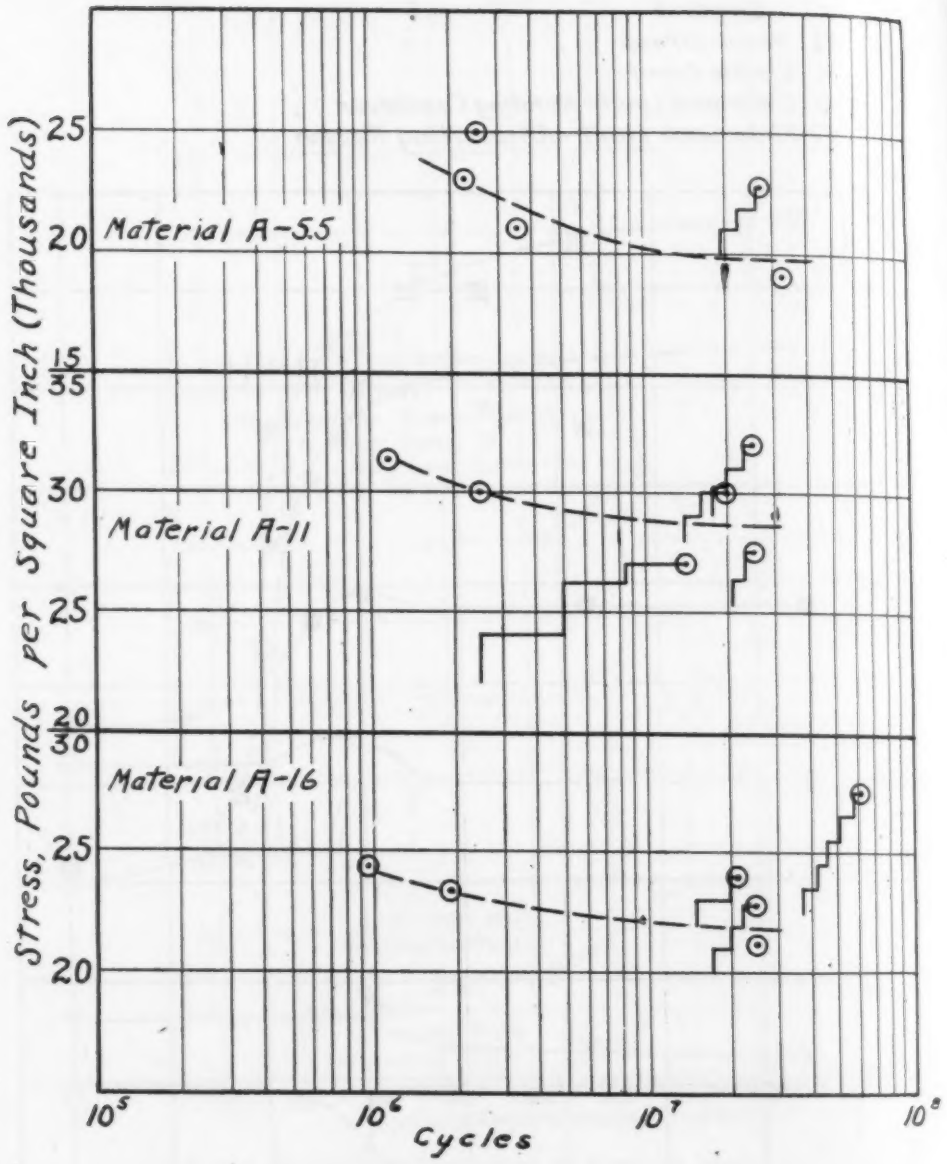

Fig. 27—Results of Alternating Torsion Tests, Nickel Material A.

21) and endurance ratio increase with increase in temperature of annealing up to 500 degrees Fahr. The curve of endurance limits in Fig. 23, however, is represented as continuing to increase between 500 and 600 degrees Fahr., the temperature of incipient recrystallization. This assumption, which is merely tentative, is based on the fact that the rotating-cantilever endurance limit of cold-worked nickel[4, 5] (Figs. 25 and 26) increases abruptly

at about the temperature of incipient recrystallization (1000-1200 degrees Fahr.,) although this annealing treatment perceptibly decreases the tensile strength.

Fig. 24 compares the effect of annealing temperature on the endurance limit of cold-worked 81:19 brass with the effect of annealing temperature on other physical properties. As shown in this figure, the proof stress and elastic limit increase rapidly with increase in annealing temperature up to 300-400 degrees Fahr.; above this temperature of annealing these physical properties decrease rapidly. Above 450 degrees Fahr., tensile strength and shearing strength decrease rapidly and the shear ratio increases. The rotating-cantilever endurance limit (as obtained from Fig. 22) increases with increase in temperature of annealing up to at least 450 degrees Fahr. As in Fig. 23, the endurance limit in Fig. 24 is represented as continuing to increase up to about 500 degrees Fahr., the temperature of incipient recrystallization of this material. The reasons for thus drawing the curve of endurance limits in Fig. 24 were discussed in describing Fig. 23.

The evidence presented in Figs. 21 to 24 inclusive, therefore, seems to indicate that the effect of cold-working on the endurance properties of brass and bronze is greatly influenced by internal stress. In the material investigated the internal stress ranged from tensile stress in the outer layer to compressive stress near the axis. Such a stress gradient has the effect of shifting the stress range applied in a rotating bend test, so that the tensile stress per cycle is greater than the compressive stress. The evidence presented in Figs. 21 to 24 indicates that this type of stress gradient, which may be designated as *positive,* lowers the nominal rotating-bend endurance limit. The effect of a *negative* internal stress gradient is being investigated. It is possible that the effect of a negative internal stress gradient on the rotating bend endurance limit is less harmful than the effect of a positive stress gradient.

It should be emphasized that, for relief of internal stress, the temperature of annealing must be carefully adjusted to the composition of the material and the degree of cold working. For more severely cold-worked brass the annealing temperatures used in the above described experiments would possibly be too high.

Effect of Cold Working on the Alternating Torsion Endurance Limit of Nickel

The previous discussion of the effect of cold working on endurance properties deals only with the rotating-bend endurance limit. Fig. 15 of a previous paper[5], gave results of some alternating-torsion tests on cold-worked nickel, materials A and CT. The results seemed to indicate that the alternating-torsion endur-

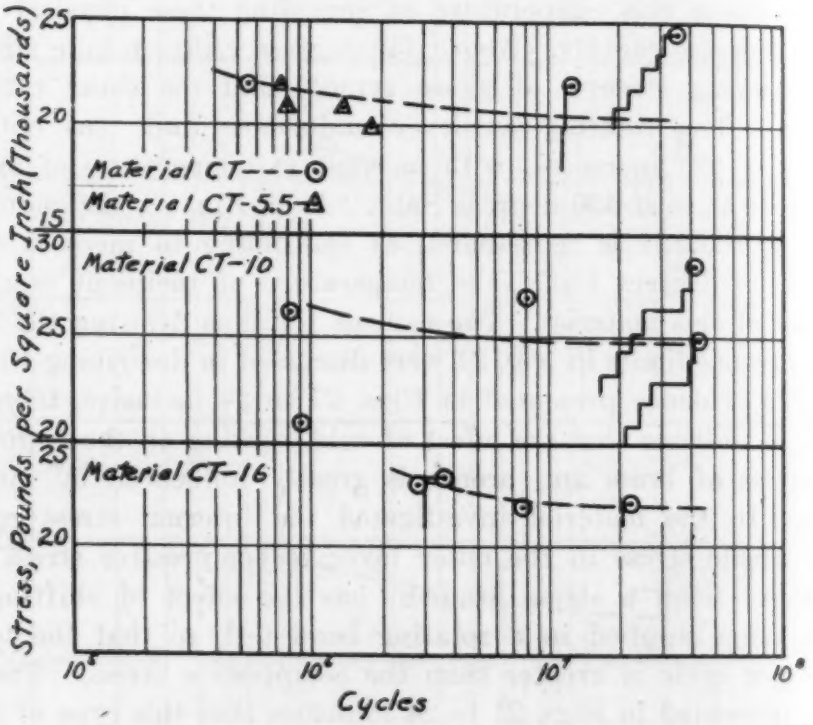

Fig. 28—Results of Alternating Torsion Tests, Nickel, Material CT.

ance limit is little, if any, higher for cold-worked than for annealed nickel. As some of these curves had been obtained with short specimens, and other with long specimens that gave a high 'sensitivity ratio',[7] it was recognized that the curves might not be comparable. Additional alternating-torsion endurance tests with materials A and CT have, therefore, been made using the same type of specimen for all tests. The results are illustrated in Figs. 27 and 28.

In Fig. 27 the upper curve represents results obtained with severely cold-worked nickel that had been annealed at 550 degrees

[7] D. J. McAdam Jr., "Accelerated Fatigue Tests and Some Endurance Properties of Metals," *Proceedings*, American Society for Testing Materials, Vol. 24, Part II, 1924.

Fahr. to relieve internal stress. The middle curve represents results obtained with material that had been annealed at 1100 degrees Fahr., which is about the temperature of incipient recrystallization. The lowest curve represents fully-annealed material. The results for the upper and lowest curve are somewhat higher than those given in Fig. 15 of a previous paper.[5] Possible reasons for this will be discussed in a later paper. The conclusions reached by comparison of the upper and lowest curves of Fig. 27 are the same as those reached by comparison of the corresponding curves in Fig. 15 of the preceeding paper.[5] Although severe cold working has increased the tensile strength of the nickel to more than twice that of fully-annealed nickel, the alternating-torsion endurance limit of the former is apparently no higher than that of the latter. Annealing at about the temperature of incipient recrystallization, however, as illustrated by the middle curve of Fig. 27, has apparently increased the alternating-torsion endurance limit at least 25 per cent. A comparison of Fig. 27 with Fig. 25, therefore, will show that annealing at the temperature of incipient recrystallization has qualitatively the same effect on the alternating-torsion endurance limit as it has on the rotating-cantilever endurance limit of nickel.

Fig. 28 shows results of alternating-torsion tests on nickel that had been less severely cold-worked than that whose endurance properties are illustrated in Fig. 27. The upper curve shows results obtained with material as received, and with material that had been annealed at 550 degrees Fahr. to relieve internal stress. The lowest curve represents fully annealed material. The middle curve represents material that had been annealed near the temperature of incipient recrystallization. The alternating-torsion endurance limit of this material as received is apparently no higher than that of fully annealed material, although the tensile strength of the former is about 60 per cent higher than that of the latter. Annealing near the temperature of incipient recrystallization, as illustrated by the middle curve of this figure, has slightly increased the endurance limit. Comparison of Figs. 26 and 28 will show that this effect is qualitatively the same as the effect of the same annealing temperature on the rotating-cantilever endurance limit.

Figs. 27 and 28, therefore, seem to indicate that cold working of nickel affects the alternating-torsion endurance limit little,

if at all, unless the cold working be followed by annealing at about the temperature of incipient recrystallization. The effect of cold working on the alternating-torsion endurance limit of nickel, therefore, is apparently very different from the effect of cold-working on the rotating-bend endurance limit. Investigation of the effect of cold working on the alternating-torsion endurance limit of other metals will be made as soon as possible.

Summary

Investigation of a number of metals and alloys, described in this and preceding papers, indicates that increasing the tensile strength by cold working to a certain limiting percentage above that of fully annealed material increases the rotating-bend endurance limit by approximately the same percentage. For nickel this limiting percentage is about 50; for copper and constantan it is at least 50. For some other metals and alloys it is possible that this limiting percentage may be different.

Increasing the tensile strength by cold working beyond the above mentioned limiting percentage increases the rotating-bend endurance limit less than in proportion to the increase in tensile strength. It is probable that with increase of tensile strength beyond the limiting percentage the rotating-bend endurance limit soon approaches a maximum.

Cold working does not appreciably increase the alternating-torsion endurance limit of nickel, unless the metal be afterward annealed about the temperature of incipient recrystallization. The effect of cold working on ductility, and the relationships of ductility to endurance limit is discussed in Part II.

PART II

History of Previous Investigation at the Naval Engineering Experiment Station

In Part I of this paper was given a brief history of the investigation previous to that time. In Part I and other previous papers it has been shown that moderate cold working increases the rotating-cantilever endurance limit in proportion to the increase in tensile strength, provided internal stress be absent. Some evidence was also presented that severe cold working does not increase the rotating-cantilever endurance limit in proportion

to the increase in tensile strength. If the rotating-cantilever endurance limit for nickel be plotted as ordinates against percentage increase of tensile strength due to cold working as abscissas, the curve begins to approach a horizontal direction as the percentage increase of tensile strength due to cold working reaches about 50. Although further evidence is needed to determine whether such a curve is typical of all cold-worked metals, it was thought desirable to investigate the effect of cold working on other physical properties. The purpose of this investigation was to discover, if possible, some relationship between the effect of cold working on the endurance limit and its effect on other physical properties.

In Part I are shown a number of graphs in which tensile strength, yield point, shearing strength, Meyer hardness indices, and other physical properties, are plotted against percentage increase of tensile strength due to cold working. The graphs of Part I represent strength and hardness values. No curves representing ductility were included, as previous investigation had indicated that the endurance limit of a metal has little relationship to ductility. A subsequent study of the results of the investigation, however, indicated that it would be desirable to present additional graphs showing the effect of cold working on ductility and on some strength values, the calculation of which involves ductility values. These additional graphs are presented in the present paper.

Material

Nearly all the graphs, Figs. 1 to 13 inclusive, represent the same material that is discussed in Part I. This material was generously supplied by the International Nickel Company, the American Brass Company, the Scovill Manufacturing Company, the Bridgeport Brass Company, the Aluminum Company of America and the American Rolling Mill Company. A few of the graphs represent material that was not described in Part I. To conserve space, tabular results of chemical and physical tests of this new material will be given in Part III.

Effect of Cold Working on Reduction of Area

The graphs of this paper illustrate the effect of cold working on ductility and on some strength values the calculation of which involves ductility values. These figures should be studied in con-

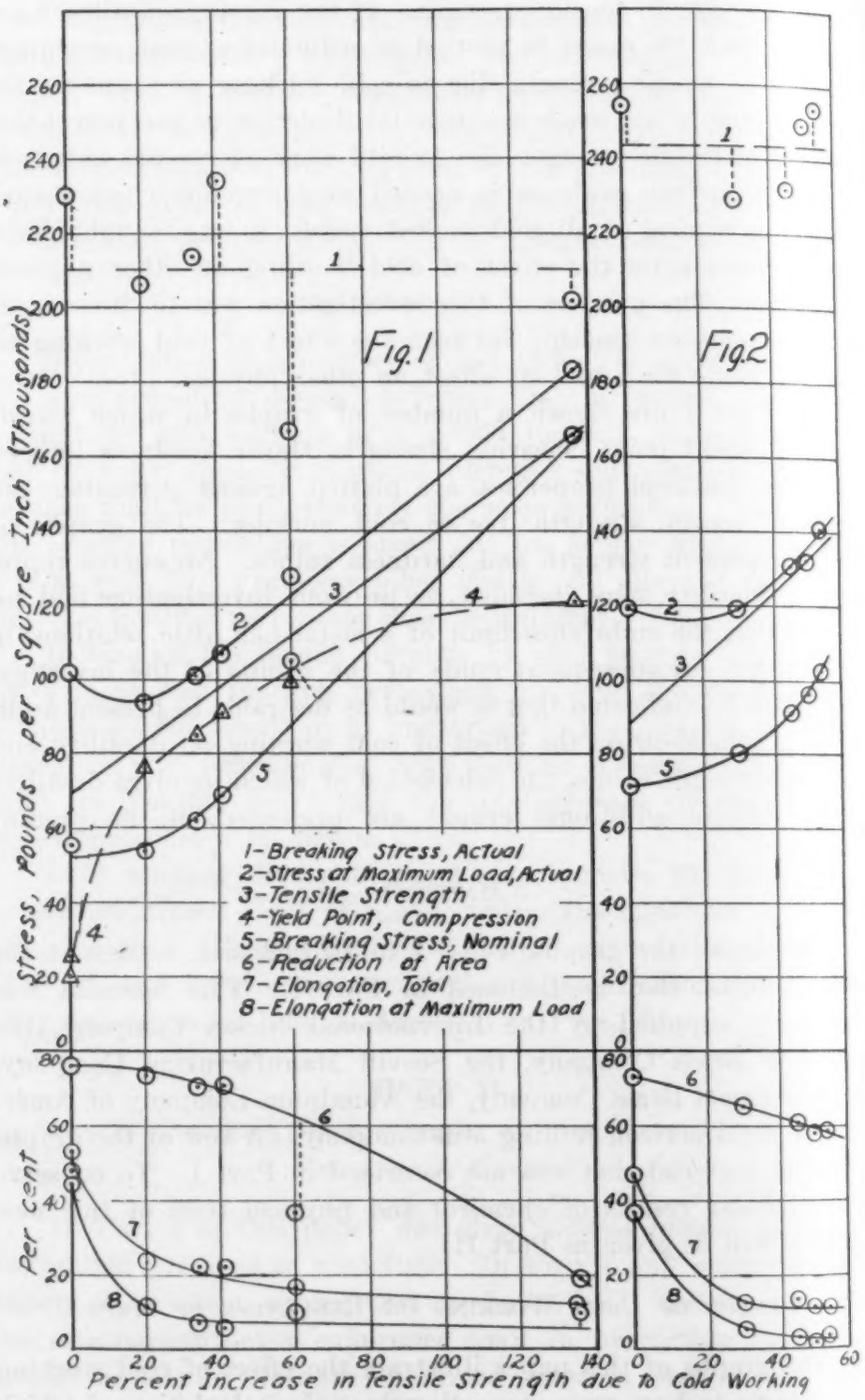

Fig. 1—Effect of Cold Working on Properties of Nickel Bars, Materials A, CT and CR. Fig. 2—Effect of Cold Working on Properties of Monel Metal Bars, Material DY.

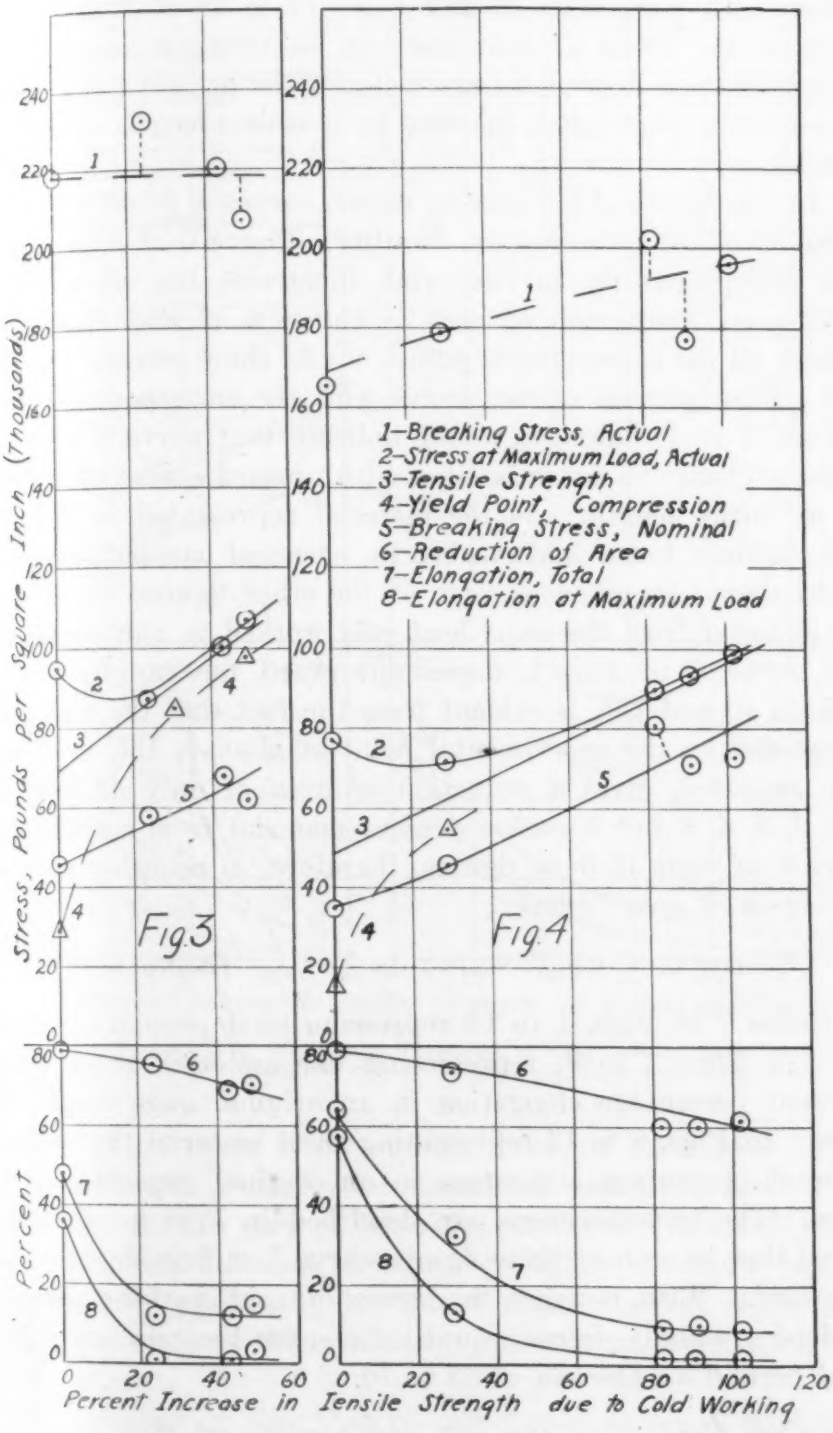

Fig. 3—Effect of Cold Working on Properties of Constantan Bars, Materials CV and CE. Fig. 4—Effect of Cold Working on Properties of 95:5 Copper-Tin Alloy Bars, Material CK.

nection with Figs. 2 to 14 and Figs. 16 to 18 of Part I, which illustrate the effect of cold working on strength and hardness. In each of these figures of Part I and of the present paper, abscissas represent percentage increase in tensile strength due to cold working.

In the figures of the present paper, curves 6, 7 and 8 illustrate the effect of cold working on ductility. Curve 6 of each of Figs. 1 to 7, representing bar material, illustrates the effect of cold working on "reduction of area." Curve 6 of Fig. 1, if drawn through all the experimental points, would show reversal of curvature. A comparison of this curve with the corresponding curves of Figs. 2 to 7, however, would indicate that curve 6 of Fig. 1 should probably be drawn as it is with upward convexity throughout its entire length. As the material represented in Fig. 1 is from various heats and varies in chemical composition, more weight should be given to some of the other figures which represent material from the same heat cold worked to various degrees. That curve 6 in Fig. 1 slopes downward too rapidly between abscissas 40 and 135, is evident from the fact that the material represented by the experimental point at abscissa 135, even when fully annealed, gives a reduction of area of only 49 per cent. Figs. 2, 4, 6, 8 and 9, each represent material from a single heat. Curve 6 of each of these figures, therefore, is probably a typical "reduction of area" curve.

Effect of Cold Working on Total "Elongation"

Curve 7 in Figs. 1 to 13 represents total percentage elongation. In Figs. 1 to 9, representing bar material, the ordinates represent percentage elongation in an original gage length of 2 inches. In Figs. 8 to 13 representing sheet material the ordinates represent percentage elongation in an original gage length of 4 inches. The test specimens are described in Part I. It will be noticed that in each of these figures curve 7 at first slopes rapidly downward. With increase in degree of cold working, however, the slope gradually decreases until the curve becomes nearly horizontal beyond an abscissa of 35 to 70.

Effect of Cold Working on Elongation at Maximum Load

Curve 8 in Figs. 1 to 13 represents percentage elongation at maximum load, the point at which the specimen begins to

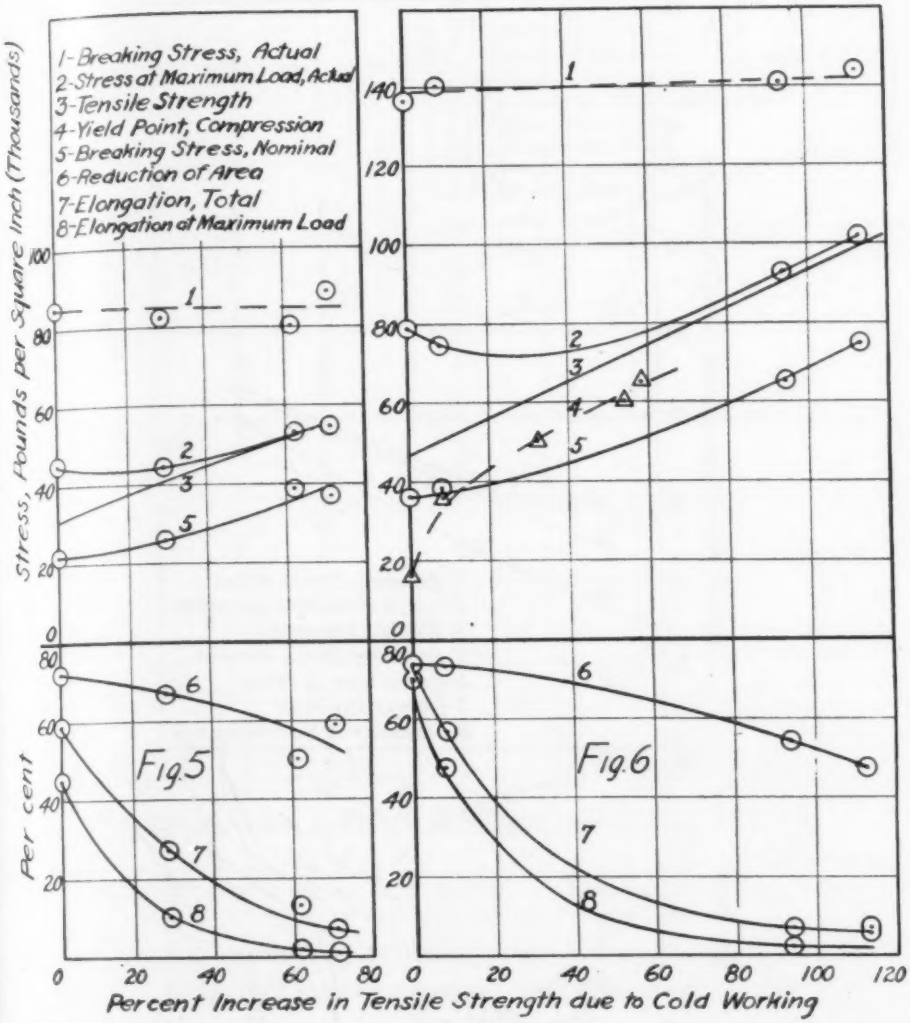

Fig. 5—Effect of Cold Working on Properties of Copper Bars, Materials BU, CL and DI. Fig. 6—Effect of Cold Working on Properties of Alpha Copper-Zinc Alloy Bars, Material CJ.

"neck." This value is determined from an automatic diagram on which a mark is made when maximum load is reached. It will be observed that in each of these figures curve 8 descends rapidly near the origin, but that the slope gradually decreases until the curve becomes practically horizontal at an abscissa of 30 to 70. Beyond this abscissa the ordinate represents an elongation of only a few per cent.

It is worthy of note that in each figure, except possibly Figs. 3, 7 and 10, the abscissa at which curve 8 becomes practically horizontal has approximately the same numerical value as the "elongation at maximum load" as determined in a tension test

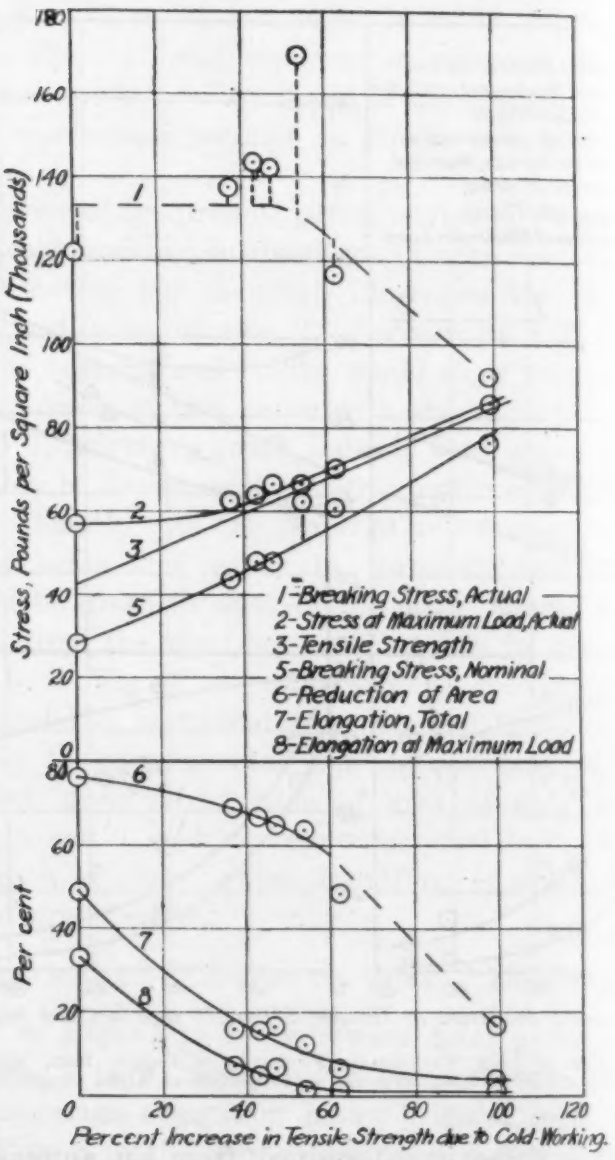

Fig. 7—Effect of Cold Working on Properties of Ingot Iron Bars, Materials BT and DQ.

of fully annealed material. In other words, the abscissa at which curve 8 becomes practically horizontal has approximately the same numerical value as the ordinate at zero abscissa. The apparent exceptions in Figs. 3, 7 and 10 are probably due to slight experimental errors. This relationship between the abscissa at which curve 8 becomes horizontal and the ordinate at zero abscissa might have been expected if the material represented by Figs. 1 to 13 had been cold worked by tension alone. If fully annealed

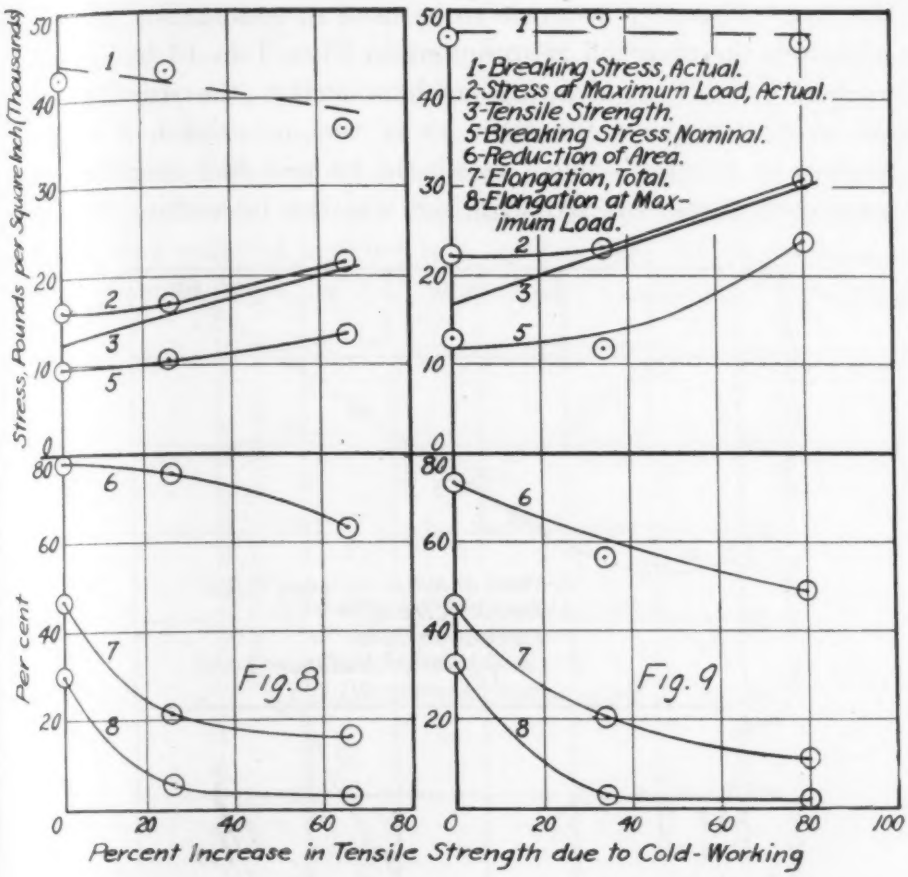

Fig. 8—Effect of Cold Working on Properties of Aluminum Bars, Material DR.
Fig. 9—Effect of Cold Working on Properties of Aluminum-Manganese Alloy Bars, Material DS.

material be cold-worked by tension alone to the point of "necking," it might be expected that a tension test specimen machined from such material would begin to "neck" without previous elongation. Actually such a specimen will elongate slightly before necking. The elongation, however, is about the same as the minimum elongation illustrated in curve 8 of Figs. 1 to 13. Material represented by the point at which curve 8 becomes nearly horizontal, is in the same condition as material that has been cold-worked by tension to the point of necking. It is evident that for previously fully annealed material, cold-worked by tension to the point of necking, the percentage increase in tensile strength due to the cold working by tension is approximately equal to the percentage elongation at that point. This relationship is only approximate, as a specimen does not remain exactly cylindrical during extension to the point of necking; nevertheless, calculations made on this assump-

tion are sufficiently accurate to be used in comparison of material. Although the material represented in Figs. 1 to 13 had been cold-worked by rolling, drawing or hammering, the ductility curves are evidently about the same as if the material had been cold-worked by tension alone. It should be possible, therefore, to express each degree of cold working, whether by rolling, drawing or

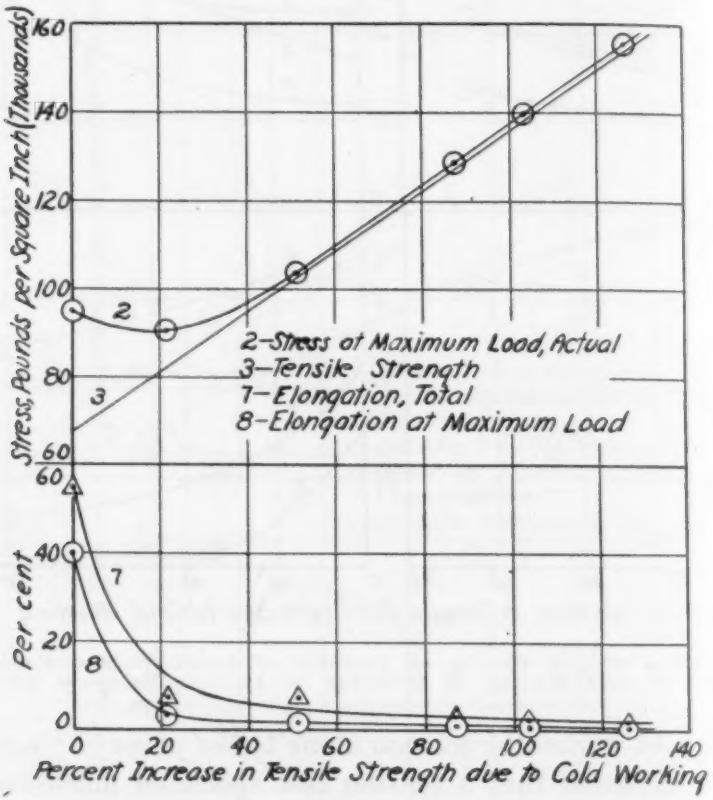

Fig. 10—Effect of Cold Working on Properties of Nickel Sheet, Material DB.

hammering, in terms of a definite stage in a tension test of fully annealed material.

A comparison of curve 8 of Figs. 1 to 13 with the curves for Meyer hardness indices in Figs. 16, 17 and 18 of Part I, shows that the curves of "elongation at maximum load" are similar in form to the curves for "n" values. It seems probable that with increase in degree of cold working the "n" value and the ductility (as represented by "elongation at maximum load") both reach an approximate minimum at about the same time. To determine, however, whether the curve of "n" values and the curve of "elongation" become practically horizontal at the same abscissa would

require many more determinations of the "n" value for a great variety of material. Beyond the abscissa at which the curve of "n" values become horizontal "n" is about 2, which means that the ratio of load to projected area of ball indentation is constant. Apparently, at this abscissa the metal is in the same condition as it is at the point of necking in a tension test. In this condition, with increase in degree of cold working by tension, the percentage

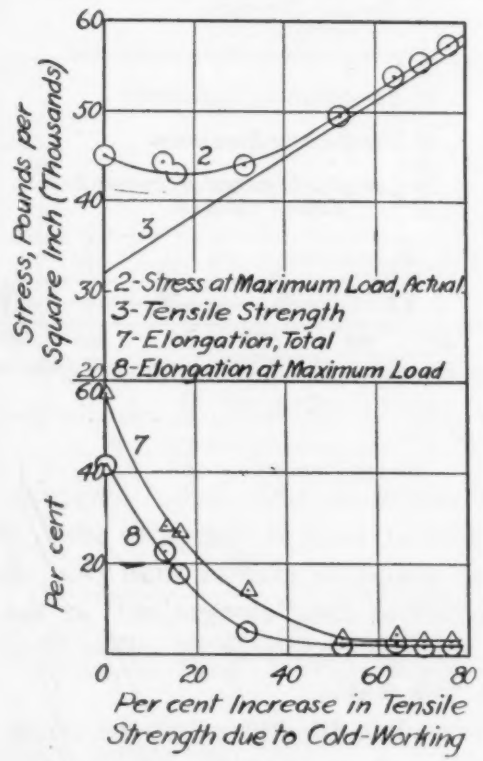

Fig. 11—Effect of Cold Working on Properties of Copper Sheet, Material DJ.

rate of increase of actual strength is just equal to the percentage rate of decrease of area of cross section.

Effect of Cold Working on Actual Stress at Maximum Load in Tension

The actual stress at maximum load in tension has been calculated on the assumption that the specimen remains cylindrical as it extends to the point of necking. As the specimen does not remain exactly cylindrical, the area of cross section at the point of necking calculated in this way is somewhat too large; nevertheless, the error is slight even in a specimen with only a 2-inch

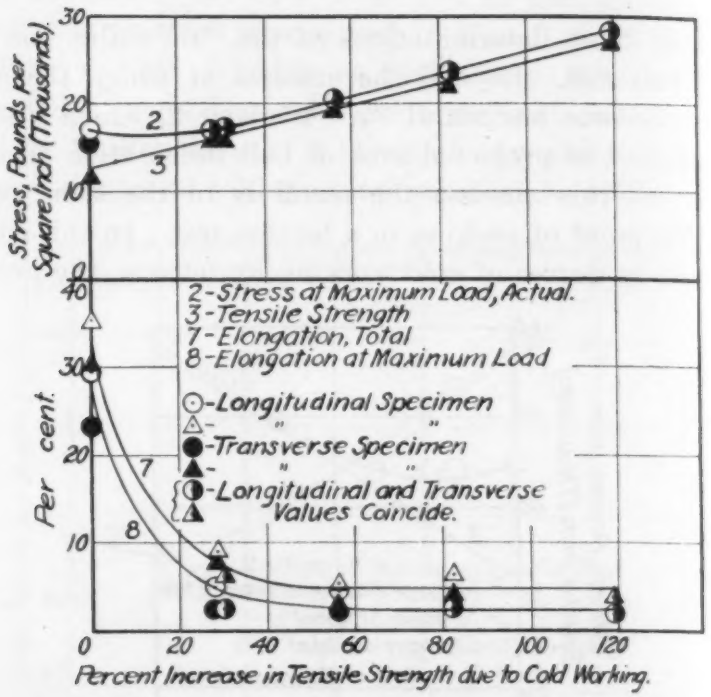

Fig. 12—Effect of Cold Working on Properties of Aluminum Sheet, Material DE.

gage length and diameter of 0.505 inch. Assuming that the specimen remains cylindrical until it begins to neck, the actual stress at point of necking would be greater than the "tensile strength" by a percentage equal to the "elongation" at the point of necking. The values for the ordinates of curve 2 in Figs. 1 to 13 were calculated in this way.

As shown in Figs. 1 to 13, curve 2 at the origin is considerably above the straight line 3 representing tensile strength. With increase in degree of cold working, curve 2 approaches line 3 until, at the abscissa at which curve 8 becomes practically horizontal, curve 2 becomes parallel to line 3. The relation of curve 2 to line 3 necessarily depends on the form of curve 8.

With few exceptions in Figs. 1 to 13 the point at which curve 2 becomes parallel to line 3 has an ordinate approximately equal to the ordinate at zero abscissa. Between these two ordinates curve 2 apparently has slight downward convexity, although in some of the figures this portion of curve 2 could be represented by a horizontal straight line. A little consideration will show that this portion of curve 2 would necessarily be a horizontal straight line if the material had been cold-worked by tension

alone. Evidently, therefore, curve 2, representing material that has been cold-worked by rolling, drawing or hammering, does not differ greatly in form from a curve representing material that has been cold-worked by tension alone.

Effect of Cold Working on Breaking Stress in Tension

Curves 1 and 5 of Figs. 1 to 9 inclusive illustrate the effect of cold working on actual and nominal breaking stress. Nominal

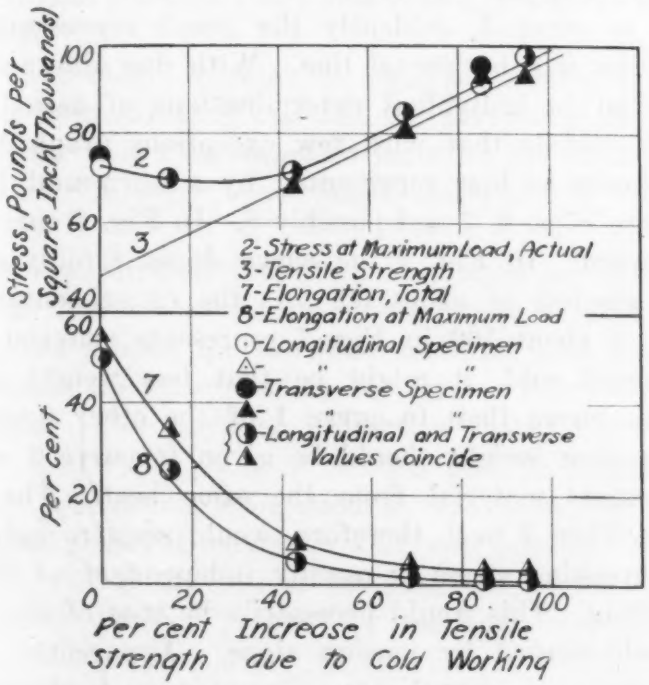

Fig. 13—Effect of Cold Working on Properties of 66:34 Brass Sheet, Material DF.

breaking stress is calculated by dividing the breaking load by the original area of cross section. Actual breaking stress is calculated by dividing the breaking load by the reduced area of cross section measured after fracture.

The curve of nominal breaking stress in Figs. 1, 2, 5, 8 and 9 is similar in form to curve 2 representing actual stress at maximum load. In Figs. 3, 4 and 7 curve 5 is more nearly parallel to curve 2 representing tensile strength. In Fig. 6 curve 5 is more nearly parallel to curve 2 than to curve 1. As for some specimens the determination of breaking load is not accurate, it is not surprising to find a variety of forms of the curve of nominal breaking stress. The evidence seems to indicate, however,

that the curve of nominal breaking stress is usually similar in form to the curve of actual stress at maximum load.

The determination of actual breaking stress is subject to considerable error due to errors in determination of breaking load and of sectional area at fracture. A curve of sectional area at fracture would be the reverse of curve 6. It would curve upward with gradually increasing slope and would be similar in form to curve 5 of Fig. 2. If the curve of sectional area at fracture is parallel to curve 5, evidently the graph representing actual breaking stress is a horizontal line. With due allowance for the wide variation in individual determinations of actual breaking stress, it is evident that with few exceptions graph 1 of Figs. 1 to 9 inclusive is best represented by a horizontal line. The exceptions are Figs. 4, 7 and possibly 8. In Fig. 4 curve 1 slopes slightly upward. In Fig. 7 the curve slopes rapidly downward beyond an abscissa of about 60. As the experimental point at an abscissa of about 100 in Fig. 7 represents material that had been hammered cold, it might be that less weight should be given to this curve than to curve 1 of the other figures. Possibly the greatest weight should be given to curve 1 of Fig. 2, which represents material from the same heat. The evidence presented in Figs. 1 to 9, therefore, would seem to indicate that the actual breaking stress is usually independent of the degree of cold working. This would necessarily be true of material that had been cold-worked by tension alone. Apparently in actual breaking stress, as in actual stress at maximum load and in ductility, cold-rolled or cold-drawn metal usually behaves like material that had been cold-worked by tension alone.

Effect of Cold Working on Yield Point in Compression

Curve 4 of Figs. 1, 3, 4 and 6 illustrates the effect of cold working on yield point in compression. Though this curve logically belongs with the graphs of Part I, the results had not been obtained at the time Part I was assembled. Curve 4 from the origin rapidly approaches line 3, representing tensile strength. Beyond an abscissa of about 30, curve 4 runs parallel to line 3. In Fig. 1, at an abscissa representing severe cold working, curve 4 again departs from curve 3. In this respect curve 4 of Fig. 1 is similar to the curve of tensile yield points in Fig. 10 of Part I.

The curves of compression yield points should be compared with the curves of tensile yield points in Part I. It will be noticed that the curves of yield points in tension and in compression are similar in form. Some of the former curves, however, become parallel to the line of tensile strength at a smaller abscissa than do the latter curves.

Conclusions

The results presented in Parts I and II lead to the following conclusions:

The percentage increase in shearing strength due to cold working is approximately one-half the percentage increase in tensile strength. For fully-annealed material the shear-ratio is 0.70 to 0.75. For severely cold-worked material the shear-ratio approaches 0.5.

If various physical properties be plotted as ordinates against 'percentage increase in tensile strength due to cold working' as abscissas, the graphs for the same material each show a critical point at about the same abscissa, or within a relatively small range of abscissas. The physical properties that show such 'critical abscissas' are, yield point in tension and in compression, yield ratio, total elongation, elongation at maximum load, Meyer's 'n' value, actual stress at maximum load, and possibly nominal breaking stress. At these critical abscissas the curves either become horizontal or become parallel to the line representing tensile strength.

The critical abscissa for the curve of elongation at maximum load is approximately equal numerically to the 'elongation at maximum load' for fully annealed material.

The critical abscissa for Meyer's 'n' value is possibly about the same as that for 'elongation at maximum load'. For the majority of metals tested, the critical abscissa for yield point in tension and in compression does not differ greatly from the critical abscissa for elongation. For some samples of sheet material the critical abscissa for yield point in tension is somewhat lower.

Investigation of the effect of cold working on endurance properties has not advanced far enough to show definitely whether or not the curve of endurance limits resembles in form any of the curves for other physical properties. Additional results of the investigation of this subject will be presented in Part III.

The curve of 'reduction of area' is horizontal at the origin, but slopes downward with increasing rapidity with increase in degree of cold working.

The actual breaking stress for cold-rolled or cold-drawn material is usually independent of the degree of cold working.

The author wishes to acknowledge the encouragement received in this work from Captain P. B. Dungan, U. S. N., Officer-in-Charge, U. S. Naval Engineering Experiment Station; also to acknowledge the assistance received from G. F. Wohlgemuth and Lawrence Thompson, associate metallurgists, and from J. L. Basil and A. P. Vandermast, laboratorians at the Naval Experiment Station.

Discussion

DR. ZAY JEFFRIES: I would like to ask Dr. McAdam if he has any explanation of the effect of cold work and recrystallization on the alternate torsion results obtained with nickel.

D. J. MCADAM, JR.:

As relatively few experiments have been made to determine the effect of cold working on alternating torsion endurance properties, I am awaiting the results of additional experiments before discussing possible reasons for the facts here presented in regard to nickel. Since, as shown in the paper, cold working raises both longitudinal and transverse tensile and shearing strength of sheet material, I was surprised to find that it did not raise the alternating-torsion endurance limit of nickel. The only property longitudinal or transverse that is not increased by cold working is ductility especially is decreased by cold working. It is possible that ductility affects the alternating-torsion endurance limit more than it affects the rotating-cantilever endurance limit, and that this accounts for the different effect of cold working on these two endurance limits. The subject, however, needs more investigation before definite conclusions can be drawn.

A. L. COLLINS: I would like to ask Dr. McAdam whether there are any figures showing the effect of tin on the endurance properties of non-ferrous alloys, particularly sheets.

D. J. MCADAM, JR.:

As shown in a preceding paper before this Society, tin when added to copper raises the endurance limit. The rate of increase in endurance limit is most rapid at small percentage of tin and the rate decreases with increase in tin content. The endurance limit of annealed ten per cent alloy is more than twice that of annealed copper.

HEAT TREATING METHODS AND APPARATUS

By C. B. Bellis

Abstract

In this article the author discusses the technique of heat treating methods and apparatus, giving the methods of a number of eastern manufacturers. A description is given of an equipment for heating tools by means of the lead bath, with figures to illustrate. The writer also discusses the use of the electric rotary furnace for small parts, the electric salt bath for rock drills and the heat treatment of wrist pins, describing two different equipments for the latter process. The question of heat treating expensive dies is also considered, the writer taking the point of view that the process that produces the best possible physical properties, regardless of cost, is the process that should be used. He describes two equipments for this process.

AN earlier article[1] described the hardening rooms of several plants in the eastern section of the United States and dealt in some detail with the management and control of the heat treating department of the "medium sized plant." The present article is concerned less with administration and more with technique. It describes the handling and hardening of a number of typical tools and parts. The methods of a number of manufacturers have been drawn upon—in some cases because the method is typical; in some cases because it is unusual or particularly good.

In a few cases the method described necessitates the use of a furnace and other apparatus made and sold only by a particular manufacturer. The names of these manufacturers cannot, of course, be given in an article of this type, but in each of these instances the method is of such outstanding efficacy as to demand description in an article purporting to tell something about how today's plants are successfully meeting their heat treating problems.

Equipment for Heating Tools by Means of the Lead Bath

One of the best continuous-production systems that I have ever seen in a small shop is to be found in the plant of a Massa-

[1] "Contemporary Heat Treating Practice," Transactions, American Society for Steel Treating, Vol. 8, No. 2, August, 1925.

The author, Clifford B. Bellis, member A. S. S. T., is consulting metallurgist, 161 Milk St., Boston.

chusetts manufacturer of cutting tools. His principal product is a special tool-steel cutter having the cutting edge at one end and a hole at the other. The cutting end is hardened in a lead pot, the remainder being left untreated.

This manufacturer has built an overhead carrier railway around the hardening room. To the "cars" are attached racks

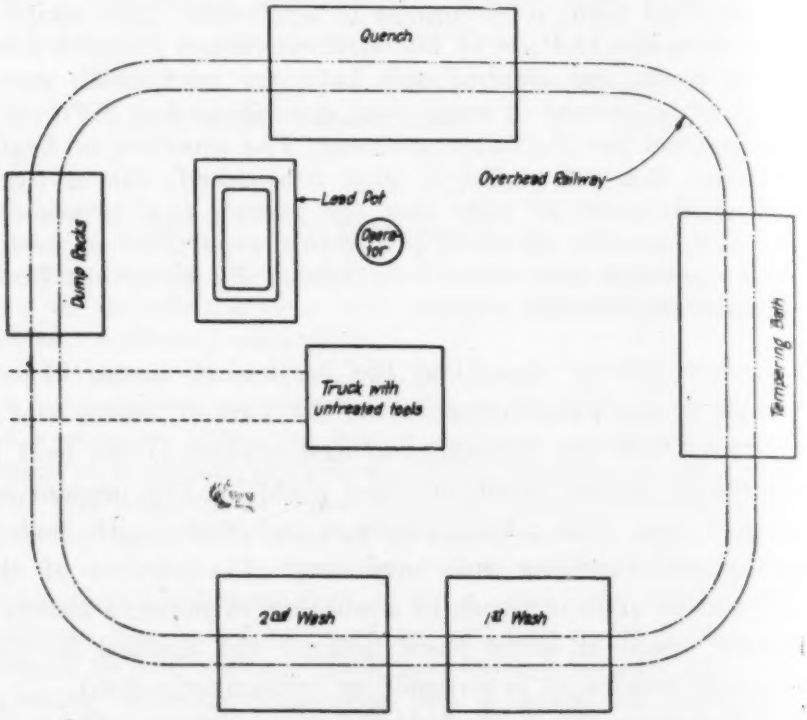

Fig. 1—Diagram Showing Handling Facilities and Arrangement of Equipment Used by an Eastern Manufacturer for Rapid Treatment of Simple Tools.

each of which carries a group of tools suspended point downward. The racks can be raised or lowered at will. The arrangement of the hardening room is shown in Fig. 1.

While it would be quite possible to immerse a rack full of tool points simultaneously in the lead pot, it has been found more expedient to attach a fixed rack to the top of the rectangular lead pot, (Fig. 2) and to set one tool in the lead pot at a time, and to remove them one at a time. This makes it possible to quench the tools individually, (an unquestionable advantage) and causes no loss of time, because the tools are inserted into and removed from the lead bath in continuous rotation. When an individual tool has been quenched it is hung upon a traveling rack

which is directly over the quenching bath. The procedure of the man at the fire, then, is to hang a tool in the lead pot, to take out the one that has been in longest, to quench it, to hang it on the traveling rack over the quench, and then to repeat the opera-

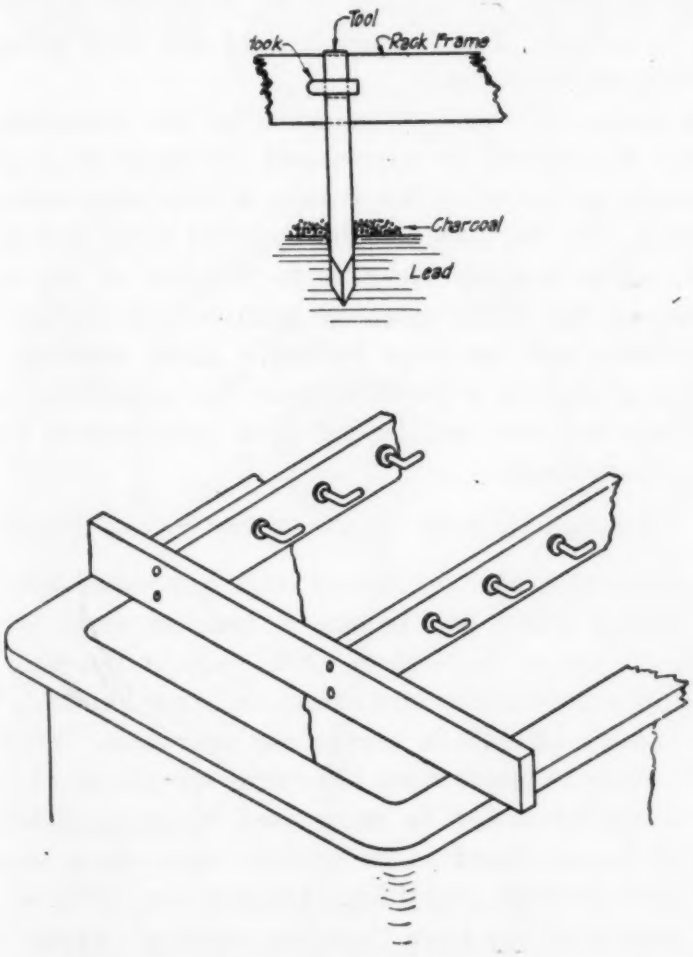

Fig. 2—Fixed Rack Over Lead Pot. Tools are Hung from Hooks The Traveling-racks, Which are Similar in Construction, are Suspended from Cars Running on Overhead Rails.

tion. The number of tools on the fixed lead bath rack is so adjusted, and the man's speed of operation is so timed that the tool which he removes from the lead pot has been in the heat just the correct length of time. A pyrometer in the lead pot and an automatic furnace temperature control apparatus maintain constant conditions of heating.

When the traveling rack at the quenching bath has been filled with hardened tools it is moved on toward the tempering

bath and another empty rack takes its place. An oil bath is used for tempering. The proper temperature is maintained by manual adjustment because the operator at this bath has less to do than the operator at the lead pot. For this reason the manager of the plant feels that the expense of an automatic control can legitimately be saved. The temperature of the bath is indicated by a steel-tube thermometer.

The proper time and temperature for the tempering operation have been determined by experiment for tools of a given model and the man in control of the process at this point lowers the rack full of tools into the bath for the specified time, and then raising the rack, sends it along the rails to the first of the wash tanks. These contain the usual cleaning solution (tri-sodium phosphate and soda ash) and are kept boiling. After washing, the racks are moved around to a position near the quenching tank where the tools are removed and loaded upon hand trucks for removal from the department.

Electric Rotary Furnace for Small Parts

The large type electric furnace with a circular floor revolving in a horizontal plane has become a familiar sight where large, heavy objects are to be heated. Not only in the steel industry, but in many others where large work is being handled, they have been found very efficient in continuous operation. Such furnaces are not common in small sizes, but there are places where a small furnace of similar design is being used to great advantage. An instance of this is found in an eastern shop where small special tools are made in large quantities. The furnace, (Fig. 3.) is almost an exact replica of the huge "electric rotaries" except for size—it is less than two feet in diameter. The resistors are fastened against the circular side walls as in the large furnaces. The speed at which the floor revolves is adjustable, and it is of course varied until a tool placed in the furnace will be just heated through to the correct temperature during one revolution. The tools are then fed continuously into the furnace through the left half of the door and removed when they again reach the door. A vertical fin of asbestos board crosses the floor at the center of the door to prevent the possibility of a tool taking a second trip through the furnace.

A somewhat similar arrangement is used in another shop

for brazing small pieces. It has been in operation for many years and is giving the greatest satisfaction.

Electric Salt Bath for Rock Drills

The writer has a client, a mining company, that hardens 3000 rock drills a day. The conditions encountered are some-

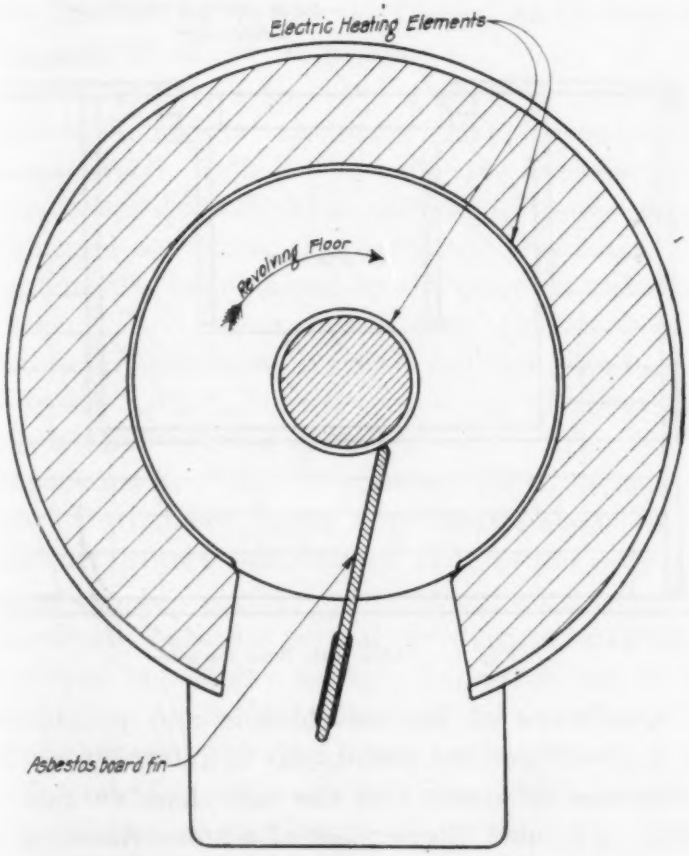

Fig. 3—Horizontal Section Through Electric Rotary Furnace for Small Ports.

what unusual, and the problem of treating the drills uniformly and economically is an interesting one. An approach to these conditions may likely obtain elsewhere, and the miners' experience should prove valuable to anyone finding himself confronted with a similar problem.

The drills are of the usual type used in mining: carbon 0.65-0.70 per cent, frequently sharpened by forging and rehardened. The work is done in a locality where the transportation of solid fuel is difficult, gas is unavailable, oil is costly, but electric power

is obtained easily and cheaply. Moderate pitting of the tools is unimportant, but steady production and moderate accuracy of quenching temperature are essential. The heating medium which is used is a salt bath heated through its own electrical resistance. It has been found to be almost perfectly fitted for the work under these conditions. The furnace used is diagrammatically shown in

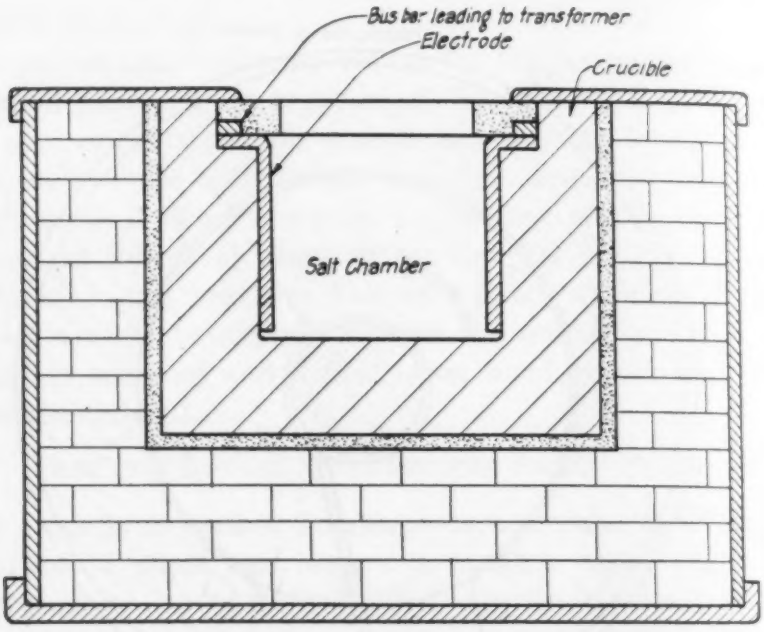

Fig. 4—Electric Salt Bath Furnace.

Fig. 4. A mixture of barium chloride and potassium chloride is used. It gives excellent results up to 1500 degrees Fahr.

The furnace is square and the salt chamber cubic in shape. The chamber is formed in one piece of a non-conducting refractory and the rest of the furnace consists, as usual, of fire brick and suitable heat insulating material. Two electrodes of Swedish iron cover two opposite interior walls of the salt chamber. These electrodes are connected to the secondary terminals of a variable voltage transformer, the primary of which is connected through suitable switches to an alternating current power supply line. In starting the furnace a carbon rod connected to one electrode is brought into contact with the other at the surface of the (frozen) salt. The arc melts the salt locally. The small pot of fused salt becomes a conductor and it is lengthened out as the rod is slowly drawn across the bath, until a small channel of molten salt con-

nects the electrodes. After that the entire chamber of salt gradually melts and comes up to the desired temperature.

The correct hardening temperature being known, and the bath maintained at that temperature, a few trials will show the length of time that the drill must be immersed to become heated thoroughly. When this figure has been obtained it becomes a simple matter to feed the drill-points into the furnace and thence into the quench, either individually or in groups.

A pyrometer thermocouple, suitably protected, should be immersed in the bath, and an automatic temperature control has been found well worth while. The protector for the pyrometer fire-end may be a steel tube closed at one end. This stands up very well at carbon steel hardening temperatures. For higher temperatures the best results are obtained by the use of a wrought-nickel protection tube. This can be made from thick-walled drawn-nickel tubing or drilled from a cylindrical bar of rolled nickel.

For a furnace having internal dimensions of about 12x12x14 inches the installation is rated at 20 kilowatts. After the furnace is up to temperature the current consumption is of course much less than this. During heating-up a voltage of about 75 is maintained; when the furnace has reached equilibrium only 10 to 20 volts are necessary.

The electric salt bath has several peculiarities and limitations that are of utmost importance to the prospective user or builder: a frequency of less than 25 cycles will give difficulty through electrolytic phenomena; chloride baths are troublesome and unsatisfactory for working temperatures above 1550 degrees Fahr.; heat losses from the surface of the bath are very high. This last point is true of all salt baths and should be taken into consideration when selecting heating methods wherever a salt bath is one of the possibilities, and when designing any type of salt bath furnace.

The emissivity of a salt bath consisting of inorganic salts is about 0.9, which means that it is a 90 per cent perfect radiator of heat (the theoretical "black body" having an emissivity of 1.0). Since a protecting layer (like charcoal) cannot be used on the surface of the bath, this factor becomes one of primary importance. I have seen a salt bath furnace designed by a group of eminent furnace engineers turn out to be a complete failure because the emissivity was assumed to be 0.5. This would have

been a more than generous estimate for most materials, but not for a salt bath. The current supply was all used up in radiating heat into the hardening room, and there was no surplus energy for doing any hardening. The moral is, of course, that if a salt bath is to be built it should be designed with an eye for the fact that the surface of the bath will be an efficient radiator. This fact has a bearing on the size of transformer to be used in the present case, and it may have a determining influence upon the

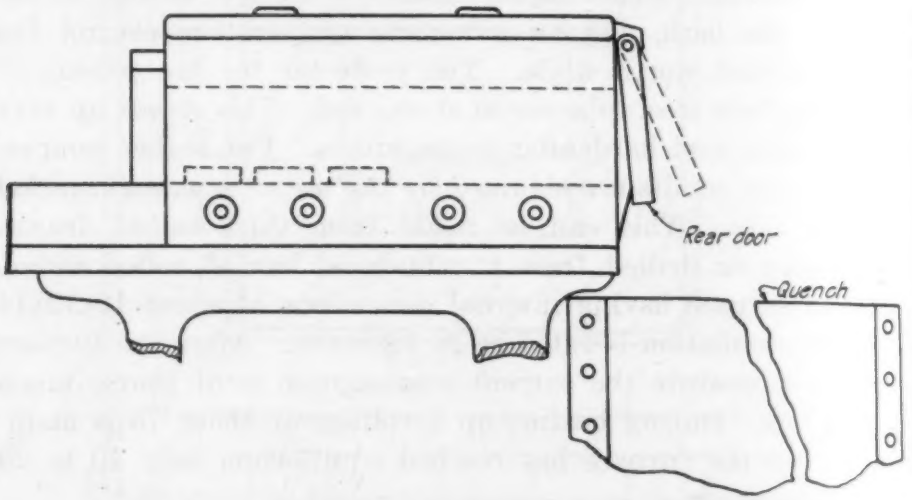

Fig. 5—Swinging Rear Door of Muffle Furnace for Wristpins.

choice of fuel or source of heat, as in the present instance where electricity is cheap.

Heat Treating Wrist Pins

Wrist pins are made in such large numbers and in so many places that it is perhaps not amiss to describe how one small manufacturer is handling them. This manufacturer frequently gets a contract to make a few thousand pins, and he has set apart one furnace for giving them the heat treatment that follows carburization. In this simple furnace, specially arranged for the purpose, one man can harden more pins than were previously treated by two men with two furnaces in the same length of time. The furnace is of the muffle or oven type (Fig. 5.) but much lower for its length than is usual for a muffle furnace. In this case the furnace is not more than six inches high (inside dimensions), while it is about 30 inches deep. Uniform temperature throughout the muffle is easily obtained. This would probably not be the

case for a homemade furnace of this shape, but a competent furnace engineer would not find great difficulty in designing such a uniformly heated muffle. It is safe to say that any good furnace manufacturer could supply the proper equipment on special order. The rear wall of the furnace may have a door of the usual type, or the rear wall of the muffle may be of light construction and hinged at its upper edge as shown in the illustration. The quenching tank is at the immediate rear of the furnace, so that pins pushed out through the back door will drop directly into it.

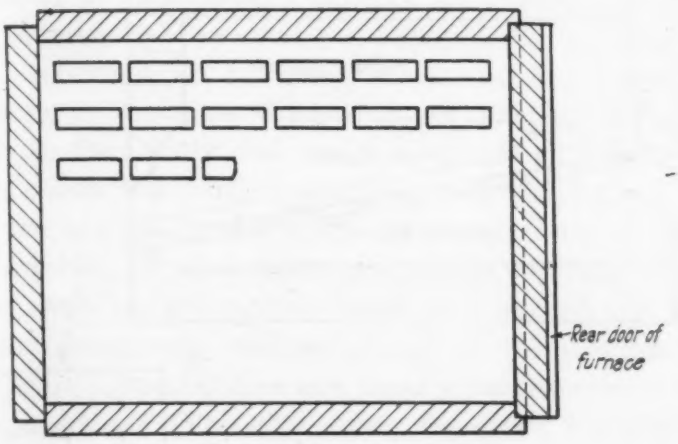

Fig. 6—Layout of Wristpins in Low Wide Muffle Furnace.

The pins are placed in the furnace end-to-end in rows extending from front to rear (Fig. 6.). Six 4-inch pins are strung like beads on a steel rod which is inserted into the furnace, lowered, and the rod is withdrawn. The next row is placed next to it in the same manner, and so on. When it is time for the first row to leave the furnace, it is pushed straight through the rear opening into the quench, and a new row is put in its place. In the regular swing of production the hardener soon learns how fast he must perform each operation to make the process continuous. that is, to have the "eldest" row ready to quench just when the latest row has been placed in the furnace.

It may seem that the row of pins will sometimes buckle when the row is pushed longitudinally out through the furnace, but there never has been any trouble of this sort, even with a plane floored furnace. Such a contingency could, however, be guarded against by the installation of a rack on the floor of the muffle, the rack having longitudinal grooves for the rows of pins to lie in.

Larger Scale Equipment for Continuous Treatment of Wrist Pins

A more pretentious apparatus for wrist pin or shackle-bolt hardening is shown in Fig. 7. Where work of this type is done continuously in considerable quantity this method has proved to

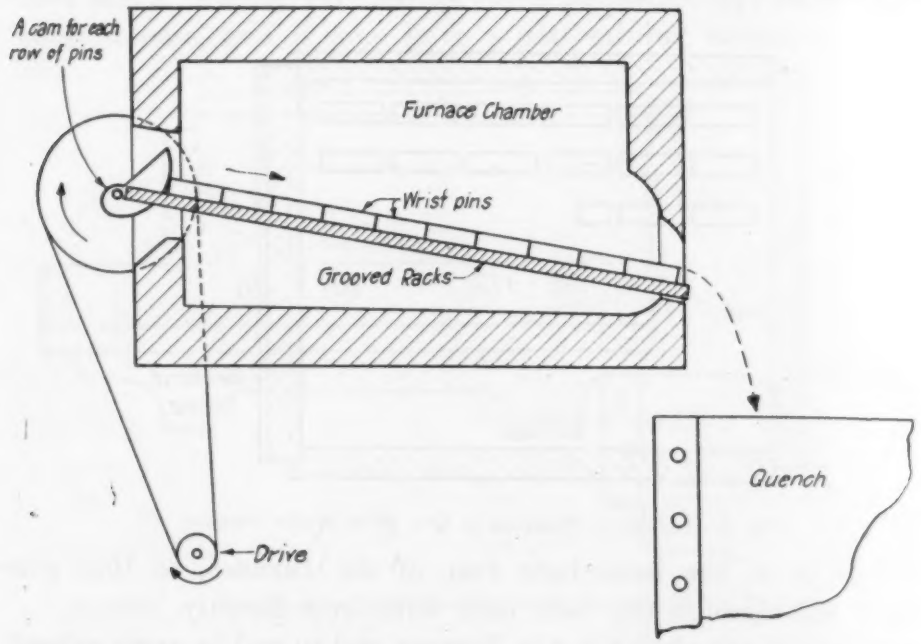

Fig. 7—An Automatic Heating and Quenching Device Used in Some of the Large Automotive Plants for Continuous Treatment of Wristpins and Shackle Bolts. This Outfit is Made by a Well-known Electric Furnace Manufacturer.

be very efficient. In one automotive plant in the middle west four of these furnaces are in regular use.

The general scheme is similar to the hand-operated method just described; the pins enter the furnace at one end and drop directly into the quench from the other. The pins in the furnace lie in longitudinal rows in grooves in a rack which is fixed in the heating chamber of the furnace and extends from door to door, sloping slightly downward toward the rear or quench end of the furnace. A cam at the front door end of each row pushes the row down the slope a pin-length at a time. At each revolution of the cam a hot pin drops into the quench, and a new pin is placed by the operator at the cam end of the row.

When the proper equilibrium has been reached between the furnace temperature and the rate of progression of the pins through

the furnace, the work of hardening is reduced to a mere feeding operation, and excellent uniformity of product is obtained.

Heat Treating Expensive Dies

The hardening of intricate or costly dies is a unique problem, far different from the choice of methods for the treatment of comparatively low-priced tools and parts. In the latter case the primary desideratum is a large volume of satisfactorily treated pieces obtained as rapidly and cheaply as possible; in the treatment of expensive dies we want the *best possible* physical properties (with absolutely no failures) at almost any price. Large dies of extremely accurate dimensions or having intricately engraved designs frequently cost many hundreds of dollars in labor before they reach the hardening room. Any saving of labor or expense in the hardening of this die is comparatively unimportant. Warping, cracking, or decarburization of the die must be avoided at any cost, and correct results must be obtained the *first time* because rehardening may reduce the life of the die considerably.

Consequently, special dies are usually hardened one at a time by the best hardener obtainable, using the finest equipment. The type of outfit most often seen (where special equipment is used for this work) is of the variety that automatically draws a curve during the heating of the die and indicates, by means of the characteristics of the curves, the time at which the die should be quenched. Two reliable American manufacturers supply patented equipment of this type and of high quality. Their two methods of obtaining curves are quite different in principle and considerable discussion may be expected regarding the relative excellence of the two methods. No opinion regarding the superiority of either one will be found in this article, but there follows a brief description of each. The two types are shown in diagrammatic form in Fig. 8.

In both cases a vertical cylindrical muffle furnace is used. In the older, and at present perhaps better known, apparatus a pyrometer thermocouple is placed adjacent to the die to be hardened. The pyrometer is of the recording variety, and as the die is heated a curve is drawn showing *temperature versus time.* When the critical temperature of the die is reached the curve bends sharply because the die for a short space of time absorbs heat without increasing in temperature, the energy going toward

the accomplishment of the change in structure of the steel. When the structure-change has ended the curve bends back again toward its normal direction. The heating is continued for a short time

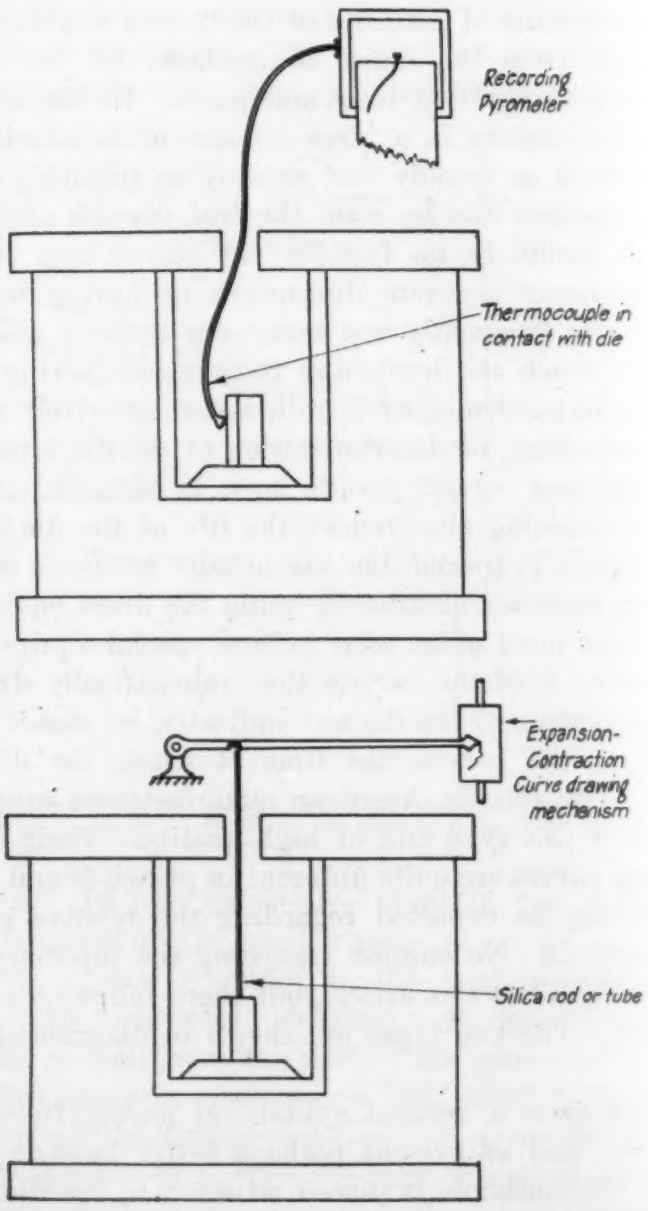

Fig. 8—Diagrammatic Representation of Two Types of Apparatus Which Draw Curves During the Heating of the Part Being Heat Treated, and Thus Indicate the Time at Which It Should be Quenched.

(the optimum time having previously been found by experiment), and then the die is removed from the furnace and quenched.

The curve-drawing mechanism in the other type of apparatus

is quite different. There is not necessarily a pyrometer in the furnace at all, but there is a mechanical device which, through a silica rod or tube in contact with the die and a system of levers outside the furnace, indicates (on a recording sheet and otherwise) any change in the dimensions of the die. The curve that is automatically drawn shows *length-of-die versus time.*

When the die is slowly coming up toward its critical tempera-

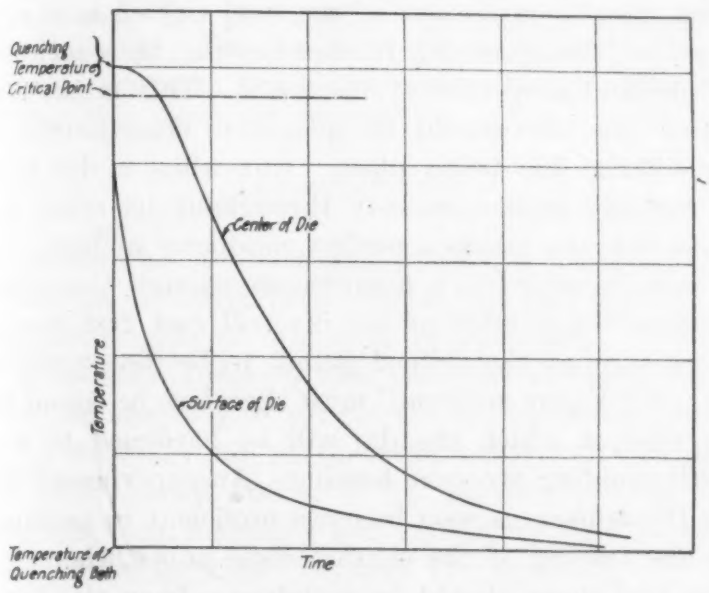

Fig. 9—Relative Cooling Curves of Center and Surface of a Quenched Die. The Slope of the Curve at Any Point Indicates the Rate of Cooling. A Certain Minimum Rate of Cooling Through the Critical Point is Necessary for Hardening.

ture the line drawn on the chart is nearly straight because the steel is expanding in proportion to the rise in temperature; but when the critical point is reached the die commences to contract, and the curve bends sharply. When the change in structure, which takes place at this point, is completed the curve bends back toward its original direction, and shortly after this the die is quenched. The indicating mechanism is equipped with a dial showing direction of dimension-change and also with electrical contacts which make possible the ringing of a bell, or the actuation of some other alarm, when the contraction of the die takes place at the critical temperature.

In the case of both of the outfits described it is customary to preheat the work in another furnace when the apparatus is

used to treat a number of dies or other articles consecutively. This makes it possible to attain a comparatively high rate of production, as only a small portion of the actual heating need be done in the curve drawing furnace.

The correct amount of heating after the critical point has been passed is the least that will provide the depth of hardening desired. It will depend upon the size of the piece and the quenching medium used. After the structure-change at the critical point has taken place the grain size of the steel (which is at a minimum at that point) increases with further heating, thus seriously affecting the physical properties of the metal. This might seem to indicate that the die should be quenched immediately after the structure-change has taken place. But when a die is quenched it does not cool instantaneously throughout its cross section because steel is by no means a perfect conductor of heat. Therefore the die must be raised to a temperature enough above the critical point so that the interior of the die will cool fast enough (as it cools down through the critical point) to be thoroughly hardened (Fig. 9). A "happy medium" must therefore be found by experiment; a time at which the die will be hardened to a sufficient depth, still avoiding excessive heating. An experienced man working with the apparatus soon becomes proficient in picking out the point in the tracing of the characteristic curve where a die of a given size and shape should be withdrawn from the furnace and quenched.

HEAT TREATMENT OF AUTOMOTIVE PARTS AND DESCRIPTION OF EQUIPMENT USED

By A. H. Frauenthal and C. S. Morgan

Abstract

This paper describes the heat treating plant of the Automobile Machine Company of Cleveland. The methods of heating, carburizing, hardening, tempering and inspecting are discussed. The plant layout, furnace equipment, temperature control apparatus, and auxiliary equipment are dealt with. The methods of operating this plant are covered.

Introduction

It is axiomatic that the life and satisfactory operation of an automobile is directly proportional to the quality of the mechanical components of which it is composed. This quality does not necessarily refer to the chemical composition of the steels but to the accuracy of dimensions and of their proper heat treatment. Practically all of the mechanical parts of an automobile are heat treated and it is the purpose of this paper to describe the methods, materials and equipment used in the plant of the Automobile Machine Company of Cleveland.

Materials Heat Treated

The principal materials and products which are heat treated in this hardening room are components which make up the rear axle, the transmission and steering mechanisms of the Chandler and Cleveland automobiles. Fig. 1 is a photograph of some of the parts which go to make up these units. Probably the longest piece which is heat treated is the rear axle drive shaft (not shown in Fig. 1). This component is approximately 30 inches long and 1⅜ inches in diameter. The relative size of the pieces shown in Fig. 1 may be readily estimated by comparing them with the large ring gear, which is 10⅝ inches in diameter and weighs about 9 pounds. Practically all of these pieces are surface-ground after they are hardened.

Of the authors, A. H. Frauenthal is chief inspector for the Chandler Motor Car Company, and C. S. Morgan is superintendent of heat treating for the Automobile Machine Company, Cleveland.

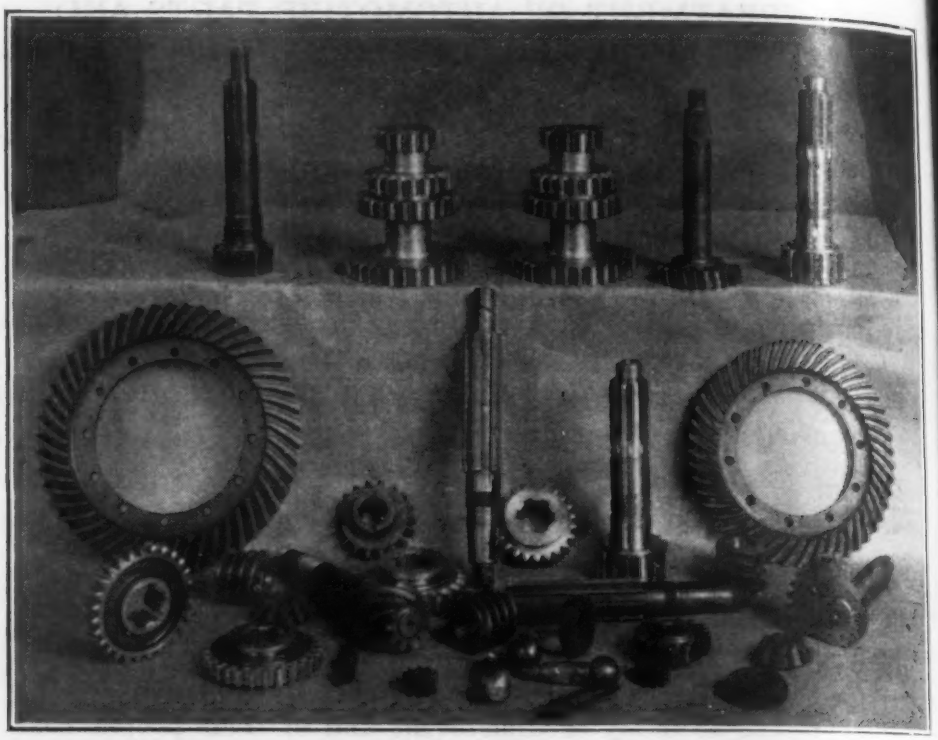

Fig. 1—Photograph Showing Some of the Various Parts which are Heat Treated in This Plant.

The following is a partial list of the materials which go through this plant and indicate the type of steel which is used:

Transmission Gears—S.A.E. 2340
Ring Gears—S.A.E. 2315
Rear Axle Drive Pinions—S.A.E. 2315
Steering Balls—S.A.E. 1020
Steering Worms—S.A.E. 1020
Steering Sectors—S.A.E. 1020
Drive Shafts—S.A.E. 3130 and 3135
Differential Side Gears—S.A.E. 1020
Differential Side Pinions—S.A.E. 2315

Arrangement of Equipment

The heat treating department is located in a modern type mill building having plenty of light from all sides, as may be observed in the accompanying photographs (Figs. 4, 5 and 6). The building is of brick and steel construction about 80 feet square, having two floors. The heat treating furnaces are located on the upper floor, while the oil storage tanks, oil cooling system, blowers and air compressors are on the lower floor. The heat treating equipment is arranged as shown in Fig. 2, and the lay-out of the lower floor is shown in Fig. 3.

Furnace Equipment

The furnace equipment consists of the following:

1 Leeds and Northrup 13-kilowatt Hump furnace
2 Leeds and Northrup 10-kilowatt Hump furnaces
7 Leeds and Northrup 5.3-kilowatt Hump furnaces
2 Leeds and Northrup tempering furnaces
3 cyanide heating furnaces, oil-fired
2 oil-fired furnaces for heating ring gears
2 oil-fired furnaces for heating drive shafts
5 carburizing or annealing furnaces, oil-fired
1 lead-pot furnace, oil-fired.
1 salt tempering bath, cast iron container 4′x4′, oil-fired.

The Auxiliary Equipment Consists of:

20 Leeds and Northrup recording potentiometers arranged as follows:
  10 potentiometers on Hump furnaces
  5 potentiometers on carburizing furnaces
  3 potentiometers on tempering furnaces
  2 potentiometers in reserve
1 shot blasting machine with revolving platform
7 oil quenching tanks
2 water quenching tanks
1 wire brush equipment
2 10,000-gallon fuel oil storage tanks
1 3000-gallon quenching oil storage tank
1 air blower for combustion air
1 cooling coil system for cooling quenching oil.
1 Brinell Hardness Tester
4 Scleroscopes
1 Rockwell Hardness Tester

Heat Treating Procedure

All the forgings received in this plant are annealed or normalized and then are shot-blasted. These forgings are then delivered to the machine shop, which is adjacent to the heat treating department, and the necessary machining operations are performed. They are then returned to the heat treating department, where they are heat treated. Those parts which are carburized are assembled at the carburizing packing bench, where they are packed into the carburizing boxes. (See Fig. 2). The parts which are hardened without previous carburization are distributed to the electric furnaces, where they are mounted on jigs or fixtures suitably designed for supporting the pieces while in the electric furnace. In quenching these pieces after they have come up to the proper heat, the entire fixture is likewise quenched. These fixtures are steel castings having steel supporting rods. Part of the transmission gears are heated at 1425

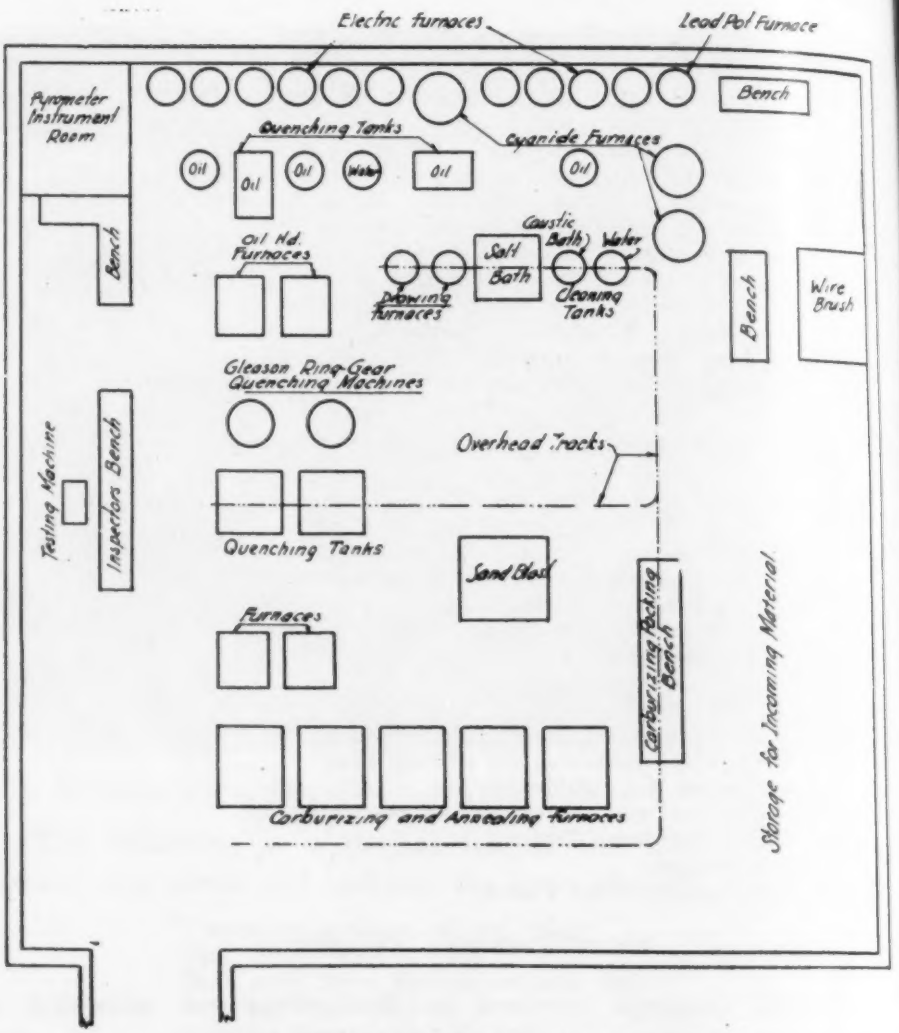

Fig. 2—Floor Plan of Heat Treating Department.

degrees Fahr. in a cyanide bath for about twenty minutes, and are then quenched in oil. The remainder are heated in the electric furnaces to about the same temperature and quenched in oil.

Carburizing

Many of the components manufactured in this plant are carburized and then hardened. The carburizing boxes used are of two types, one the circular chimney type, and the other the rectangular type. These are cast steel boxes. It has been found in this plant that the life of these boxes is between 1000 and 1200 hours. Two sizes of rectangular boxes are used. With the

smaller type it is possible to arrange 12 boxes in each furnace; with the larger size 6 may be charged into a furnace, and in addition 3 chimney-type boxes. The chimney-type box is used exclusively for carburizing the large differential ring gears.

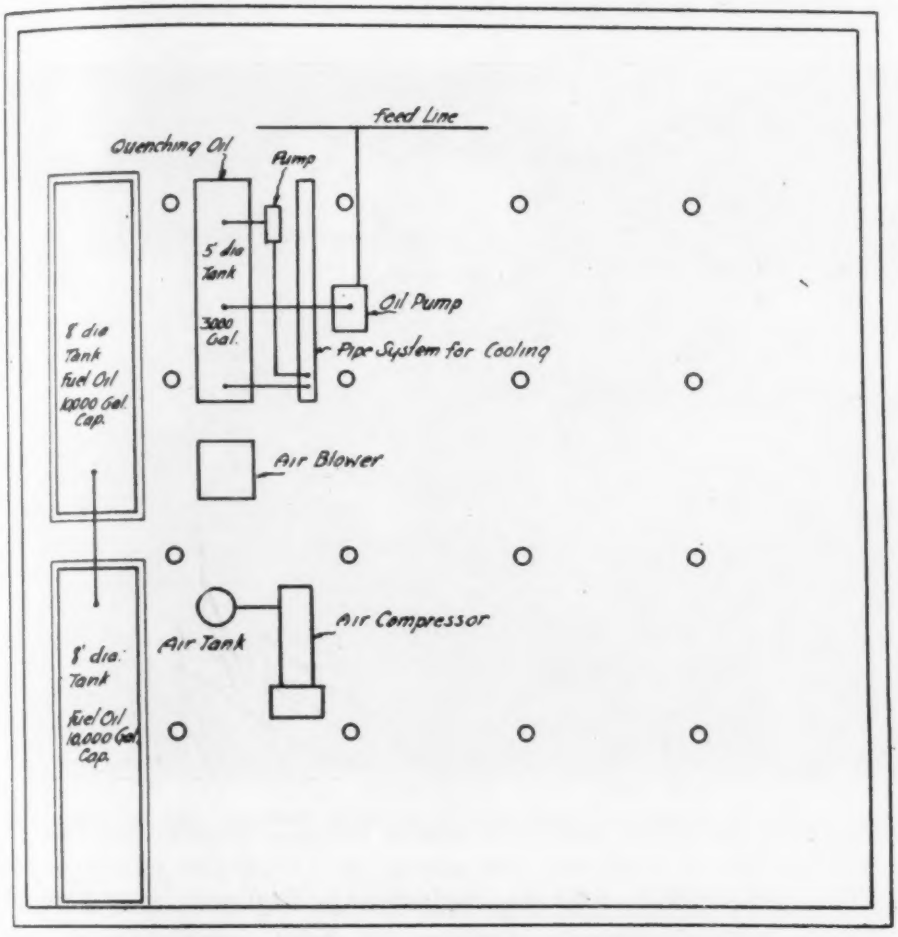

Fig. 3—Floor Plan of Lower Floor, Showing Arrangement of Storage Tanks, Cooling System, Blower and Air Compressor.

A standard commercial carburizing compound is used. The practice followed is to use two parts of old compound to one of new. After each run the compound is sifted, and the coarse material is then considered old compound, and is placed in a storage bin. The pieces are packed into the boxes and the covers are luted on with a mixture of one part shot blast scale dust and one part fire clay. Excellent results have been obtained with this luting mixture, and shrinkage cracks are eliminated.

The carburizing furnace equipment consists of 5 oil-fired furnaces of the under-fired type. Each furnace occupies a floor space 82x124 inches having a hearth opening of 48 inches wide by 23 inches high, the depth of the heating chamber being 72 inches. The furnaces are equipped with 3 oil burners, two burners in the front and one in the rear. (Fig. 4).

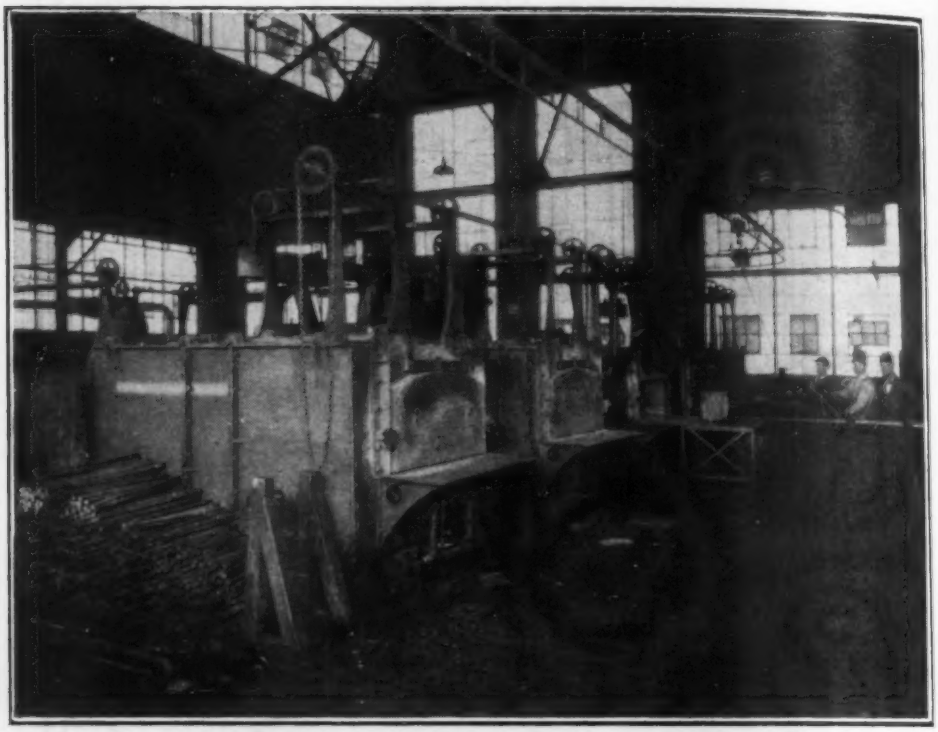

Fig. 4—View of Battery of Carburizing and Annealing Furnaces. The Carburizing Boxes are Brought to the Furnaces by Means of the Overhead Tracks, which can be Clearly Seen.

The temperature of the carburizing furnaces is controlled by Leeds and Northrup potentiometer light signal system; the potentiometers being housed in a separate room as can be seen in Fig. 2. The parts are carburized for the required length of time at 1625 to 1675 degrees Fahr. After carburizing, the furnace is discharged, the boxes being conveyed by means of the overhead track conveyor to the cooling floor. Ninety per cent of all the materials which are here carburized are cooled in the boxes, after which they are heat treated. In this plant no double heat treatment is used on any of the carburized components. About 10 per cent of the carburized pieces are quenched directly from the box. Fig. 4 shows the battery of carburizing and annealing fur-

naces. One of the furnaces is in the process of being charged. These same furnaces are also used for annealing.

Hardening of Carburized Parts

After the boxes have cooled, they are dumped, and the parts are then mounted on fixtures for heat treatment in the electric furnaces. These furnaces are of the Hump type, and are controlled by means of a light signal system. An operator constantly observes the charts in the instrument room, and when the "hump" has been reached on a given furnace, the temperature is allowed to increase about 70 degrees Fahr. above the hump. Duplicate sets of lights are arranged, one above the recorder and the other above the heating furnace. (Fig. 6). When the instrument man observes that the parts have been properly heated he rings a bell, then pushes a button which lights the red light over the potentiometer and likewise over the furnace. The operator then proceeds to quench the parts which are in that particular electric furnace. Quenching tanks are conveniently arranged directly across the aisle from the electric furnaces. As soon as the furnace has been unloaded, the operator again charges it with cold material and pushes a button which lights the blue light over the potentiometer and the furnace. In this way the instrument operator is then notified that the furnace is again ready to be turned on.

Most of the materials which are hardened in this plant are quenched in oil. After quenching they are tempered either in electric furnaces or in salt bath tempering furnaces. In tempering with the salt bath, the pieces are placed in a wire basket and are submerged in the heated salt and held at 350 to 400 degrees Fahr. for 1 hour. After tempering they are immersed into a hot caustic cleaning mixture, and then into water. This cleaning mixture has been developed by this company, and consists of the following:

25 per cent caustic soda.
35 per cent trisodium phosphate.
35 per cent sodium carbonate.
5 per cent rosin.

The parts are then taken to the wire brush department, where they are brushed to remove any adhering scale. From this department they are taken to the inspection bench, where they

Fig. 5—Photograph Showing Heating Furnaces and Gleason Quenching Machines Used in the Hardening of Differential Ring Gears. The Operator has Just Quenched a Gear.

are observed for cracks and tested for hardness. Three different hardness testing machines are used: the Brinell, the scleroscope and the Rockwell. After this inspection the pieces are delivered to the machine shop for the final operations.

Gleason Quenching Machine

The large differential ring gears are not hardened in the electric furnaces, but instead are hardened in oil-fired furnaces to the temperature of 1380 degrees Fahr. Two of these furnaces are provided, each occupying a floor space of 64 x 100 inches. They have a heating chamber of 33 inches wide by 14 inches high and 48 inches deep. They are heated by two oil burners—one in the front and the other in the rear, and are under-fired. These furnaces are furnished with automatic potentiometer recorders. Each time a gear is removed for quenching, another cold gear is placed in the furnace on the opposite side and in successive operations is pushed along the side to the rear, across the rear and down the other side, reaching the proper temperature near the door of the furnace and on the opposite side from loading.

Fig. 6—View Showing the Battery of Electric Heating Furnaces in which the Greater Part of the Material is Heated. The Furnaces, which are Covered with Hoods, are Cyanide Salt Furnaces. The Large Brick Construction on the Right is a Salt Bath Tempering Furnace. The Operator is Lowering a Basket of Parts into the Bath. The Bath Baskets are Conveyed to the Furnaces by Means of an Overhead Track System.

When the gear has reached this point it is removed from the furnace and is placed in the Gleason quenching machine and quenched in oil (Fig. 5). The purpose of this machine is to reduce to a minimum any distortion or warping of the gear.

Hardening Rear Axle Drive Shafts

The rear axle drive shafts are hardened in oil-fired furnaces, and are quenched endwise in water. After the hardening process they are tempered and then inspected for hardening cracks and tested for hardness. Should the shafts be warped, they are straightened on a straightening machine.

Heating Methods

Two methods of heating for hardening are employed, the electric and the fuel oil. In the case of the fuel oil, two 10,000-gallon tanks are mounted in cradles on the lower floor of the

building. Each tank has a capacity somewhat greater than an oil tank-car. The oil is supplied to the furnace by means of rotary pumps. For convenience in refilling the tanks, a pipe line has been run to the railroad siding where the tank car is connected and drained into the storage tanks. If for any reason it should be necessary to drain either or both of the tanks, it is possible for an operator to get under them and open the drain plugs. One of the chief advantages for having the fuel oil storage tanks in the basement is that the temperature of the fuel oil does not drop to freezing or below, as is sometimes the case when the tanks are buried in the ground.

A rotary air blower is provided for supplying the combustion air to the oil-fired furnaces.

Quenching Oil System

The oil quenching system is of the continuous flow type, having a 3000-gallon storage tank. This tank, as stated before, is mounted on the lower floor. The quenching oil is maintained at a temperature of 110 to 120 degrees Fahr. This temperature is kept between these two points by means of a pipe cooling system. The oil is passed through pipes which are surrounded by a water jacket. The amount of oil which flows through the pipes and the temperature of the water jacket regulate the temperature of the oil. The speed of the oil pump is adjusted so that the proper temperature is maintained at all times. With an increase in the temperature of the water jacket, the rate of flow through the pipe is decreased.

This plant is operated on a two-shift 24 hour basis and employs a total of about 30 men. Approximately 300 steering, transmission and rear axle units are manufactured each day. These units are manufactured for use on the Chandler and Cleveland automobiles.

Comment and Discussion

Papers and Articles Presented Before the Society and Published in Transactions Are Open to Comment and Criticism in This Column—Members Submitting Discussions Are Requested to give Their Names and Addresses.

ON HIGH POWER PHOTOMICROGRAPHY

By Colonel N. T. Belaiew

MAY I be permitted to add a few comments on the question of high power photomicrography, which, of late, has been brought into the foreground by the work of F. F. Lucas?

In my early researches on crystallization of steel and of the various components thereof I used in accordance with the established practice magnifications up to 1000 diameters. It was only in 1920, when having restarted some investigations on pearlite, did I become convinced that, under circumstances, still higher magnifications would be useful.

In a paper on "The Inner Structure of the Pearlite Grain,"[1] I advanced the view on the stereometry of the pearlite grain, which enabled me to calculate the actual distances Δ_0 between the cementite lamellæ and, consequently, the actual widths of such lamellæ.

As in usual pearlitic specimens the former are of the order of 300$\mu\mu$, the latter would be of about 100$\mu\mu$.

As I am using a 2-millimeter Leitz oil-immersion apochromatic lens of a numerical aperature of 1.32, and as the wavelength of light used is 450$\mu\mu$, the reciprocal of resolution "d" will be equal to 450$\mu\mu$, divided by 1.32 × 2, or 170$\mu\mu$.[2] Thus, lengths of about 100$\mu\mu$ would be smaller than the resolving power and would appear as blurred lines of a width not less than 170$\mu\mu$.

These theoretical considerations might be easily tested on suitably selected specimens of pearlite, and this was done on some of the specimens of slowly cooled steels, as explained in the paper just mentioned.[3]

[1] *Journal*, Iron and Steel Institute, 1922, No. I, Vol. 105, pp. 202-227.
[2] Loco Cit., p. 221.
[3] Loco Cit., pp. 220, 221.

The author, Colonel N. T. Belaiew, is consulting metallurgist, 33 Elvaston Place, Queen's Gate, London, England.

Comparing high power photomicrographs of alloys Nos. 1 ($\triangle_0 = 1.25\mu$) and 8 ($350\mu\mu$) on Figs. 10 and 26, it was found that the measured width of the cementite lamella of the alloy No. 8 was about $220\mu\mu$, whereas the calculated one, as previously mentioned, is only $100\mu\mu$. On the other hand, the measurements effected on Fig. 26 (3000×) give for the alloy No. 1 —$330\mu\mu$, which agrees well with the calculated limits of between $300\mu\mu$ to $400\mu\mu$. This also explains why the ferrite lamellæ of Fig. 26 seem wider than those of Fig. 10 (4500×).

Thus, in actual practice with the optical system mentioned it is possible to get resolutions which are rather close to those theoretically arrived at, i. e., in my case to about $200\mu\mu$. Investigators and laboratories equipped with better appliances could aim even at, say, 150-$170\mu\mu$. However, considerable skill will be required for taking use of such opportunities, and I would like to take this opportunity to say how much indebted I feel to my colleague, Captain Brandt, for his assistance.

In actual practice, taking photographs with the lens and the source of light mentioned, it has been observed that the best negatives are obtained at magnifications of about 1000. Thus, for high power photomicrography this magnification was taken as the standard one for negatives. On reproduction it was, however, observed soon that details are lost and, at any rate, eyesight has to be strained if the black lines are thinner than about ½ millimeter; that brings us to 3000d. If we desire a network of thinner lines, it is better to stop at 2000; if, on the other hand, we are satisfied with thicker lines, 4000 may be used. All these magnifications were reproduced in the already mentioned paper, and in the latest one read[4] at the Royal Society in May, 1925. I think that for reproduction purposes I would be inclined now to consider the 3000 as giving the better results.[5]

In this last mentioned paper the question of the "ferrite cubes" is treated at some length. I think that I can say that my observations from 1921 till this year are in complete accordance with those of Lucas, and that the "cubes" are well within the range of observation.

[4]"On the Inner Crystalline Structure of Ferrite and Cementite in Pearlite." *Proceedings*, Royal Society, A, Vol. 108, 1925, pp. 295-306.

[5]Loco Cit., Plate 10, Fig. 1.

NOTES FROM U. S. BUREAU OF MINES

Cementation of Copper by Sponge Iron

SPONGE iron has many advantages over scrap iron as a precipitant for copper. The Bureau of Mines, Department of Commerce, has completed an investigation covering the rate of precipitation, grade of product obtainable, completeness of precipitation and effects of temperature and acidity, using various sponge iron products under different conditions. It was found that sponge iron precipitates copper much more rapidly than does scrap iron or detinned scrap. On account of the fine state of subdivision of the sponge iron, the precipitation must be carried out in apparatus designed for that purpose. These facts, brought out in the earlier tests, have been confirmed by a series of tests just completed.

Production of Steel by Direct Processes

The Bureau of Mines, Department of Commerce, has for some time been working on the problem of sponge iron production by several promising methods. This work, which was being conducted at the North-West Experiment Station, Seattle, Washington, was, at the beginning of the present fiscal year, transferred to the North-Central Experiment Station, Minneapolis, Minn. In the laboratories of the Minneapolis station work has been conducted during the past year on the factors affecting the time rate of iron ore reduction. The results of these experiments are applicable to the sponge iron investigation and will therefore be continued, giving the station a means of interpreting scientifically the results obtained in the sponge iron experiments.

A number of other investigations on the metallization of iron ore and on the production of sponge iron are being carried on. Thought has been given to outlining the future work of the Bureau of Mines along these lines in such a manner that it may best fit in with the problem of production of steel by direct process considered as a whole. Attention has also been given to the best methods of utilizing the products from the metallizing process and to the economics of these processes with respect to the utilization of low grade iron ore.

Barium Polysulphide as a Sulphidizing Reagent

The results of a study of the possibilities of barium polysulphide in sulphidizing oxidized ores for flotation are given in Serial 2698, recently issued by the Bureau of Mines, Department of Commerce. The sulphidizing filming of minerals in oxide ores as a preliminary treatment to aid their recovery by flotation is known practice, state Edmund S. Leaver, metallurgist, and Horace M. Lawrence, associate metallurgist, the authors. In this work the use of barium polysulphide does not appear to have been considered. A study of the properties of barium led to comparative investigation of the sulphides and polysulphides of the alkaline and alkaline-earth metals. For the investigation two fairly typical oxidized ores of copper and lead were selected.

From the results of the Bureau of Mines investigation it would appear that barium polysulphide has possibilities as a sulphidizing reagent. On the

copper ore the extraction and grade of concentrates were about as good as were obtained from any of the sulphidizing reagents used. On the lead ore, however, barium polysulphide did not give as high an extraction as was obtained with a combination of sodium sulphide and polysulphide, or a sodium sulphide-paraffin mixture. Barium polysulphide prepared by either of two methods seemed to have about the same sulphidizing effect. In districts where deposits of barite occur, barium polysulphide might be prepared cheaply, and prove to be a satisfactory sulphidizing reagent.

Of other sulphidizing reagents considered in this investigation sodium sulphide and sodium polysulphide, either separately or as a combination, gave the best results. Calcium polysulphide used alone did not yield as good results as had been expected, as it has been somewhat favored in the past by investigators, partly because of its comparative cheapness. Sodium sulphide and calcium polysulphide as a combination proved to be satisfactory for the copper ore, and at least one of the companies treating oxidized copper ores uses this combination successfully. Potassium and ammonium polysulphides are too expensive for commercial practice, particularly as at least equal or larger amounts of these reagents are needed than is required with the cheaper sulphidizing reagents. In no case in the amounts used did hydrogen sulphide prove to be as satisfactory a sulphidizing reagent as some of the others. Also, as only the amount of gas actually absorbed in water was determined, the total amount of hydrogen sulphide gas generated was much higher.

Revolving Screens for Mine Use

Of the four main classes of screens the class that has received most attention is called a revolving or roller screen at coal tipples and a trommel or drum screen in ore-dressing plants. Such screens are common equipment at ore mills where perfect screening is more important than speed, and where wet screening is usual for the sizes ranging from 15 to 2 mm. Revolving screens are so likely to break friable coal, however, that they are not favored for coal sizing and are not being installed in new plants. For coal sizing they usually take a dry feed, unless used in a washery. A revolving screen in its simplest form is a cylindrical frame with an envelope of wire screen cloth, perforated plate, or even bars, and with its longitudinal axis set at a slight angle. The screen receives material at the upper end, discharging the oversize at the lower end; it revolves slowly, and carries the particles of material up the rising side until gravity overcomes both their friction against the screening surface and any centrifugal force given them by rotation. Each particle rolls or slides down until it comes to rest and then is carried up the slope again. Detailed descriptions of various types of revolving screens are given in Bulletin 234, recently issued by the Bureau of Mines, Department of Commerce.

Types of Flotation Reagents

The reagents employed in flotation work are of two types, one being known as "Flotation controlling" agents, and the other, as "flotation" agents, states the Bureau of Mines, Department of Commerce, in Serial 2700, just issued.

"Flotation controlling" agents are those substances or chemicals of the inorganic class, that are added to the ground ore-water pulp to add vigor to the floatibility of a particular mineral, or to decrease the floatibility of a particular mineral.

"Flotation" agents are those substances, invariably of organic nature, that cover the mineral particles with a film that permits them to be caught by the bubbles injected into the pulp. Another property of such substances is tc lower the surface tension of the water, thus permitting the formation of small bubbles and a froth.

Generally speaking, the controlling agents should be and are added to the pulp at some point in the mill prior to the addition of the oils. Sometimes chemicals, such as lime, are added to the ore as it is dumped into the mill feed bins, but as a rule the controlling agents are added to the fine grinding ball mills. The oils, if they are heavy and difficult to incorporate, may be added with the controlling agents to the same grinding mill. This would not seem to be good practice, but it is often done. Again, in many plants the reagents are mixed with the ore pulp in separate agitators.

The time of reaction required for controlling agents to impart the desired change in surface properties to the respective minerals present, depends upon the ore being treated and the controlling agent found suitable for its treatment. With most reagents, and most products, a "conditioning" period of one to five minutes generally is sufficient. In the treatment of a collective float concentrate of two minerals, A and B, to be separated into A and B concentrates, where, say, A is to be floated and B is to be suppressed; a conditioning period of several minutes to a half hour may be necessary.

Where sodium or potassium xanthate is the reagent, it is fed direct into the first cell of the flotation machine and a conditioning period of any consequence does not seem to be required.

Abstracts of Technical Articles

Brief Reviews of Publications of Interest to Metallurgists and Steel Treaters

IMPROVEMENTS IN AUTOMOTIVE STEELS. By W. G. Hildorf, metallurgist, Reo Motor Car Co., Lansing, Mich., in *Iron Age*, November, 19 1925, page 1378, and November 26, 1925, page 1448.

This paper was presented at the fall meeting of the American Gear Manufacturing Association at West Baden Ind., October 1 to 3. In the first part of the article the author discusses the difficulties due to seams and dirty steel, "normal" and "abnormal" steels, and the effect of heat treatment. In the second part he discusses the subjects of determining fatigue values by fractures, variations in grain size, and the fact that fine-grained steels are better. He maintains that it should be possible to obtain a more uniformly dense structure, that there should be more improvements made in the cleanliness of steel, and that, as "abnormal" steel is more prone to give soft spots than "normal" steel, "abnormal" steels ought to be eliminated. He also states that since grain size varies greatly from heat to heat, considerable work needs to be done along this line. Illustrations are given to bring out the various points discussed.

MOLYBDENUM—AS AN ALLOY OF STEEL. By R. C. Rowe, mining engineer, Quebec, in *Canadian Machinery*, November 26, 1925, page 13.

In this article the author discusses nickel-chromium-molybdenum steels, which, although only recently developed, have become definitely established among the other industrial alloys. The metal molybdenum, so far as is known, does not occur in the native state, but is obtained mainly from the disulphide, molybdenite. Prior to 1914 the main sources of supply were Australia and Norway, but since then the United States and Canada have become heavy producers. The main deposits in Canada occur in Ontario and Quebec.

Two methods of reducing to metal are given. The one mainly used being the alumni-thermic process, the other, the electric fusion process. A further method is in electric furnaces with iron. Pure molybdenum is silvery white, malleable, and will not scratch glass. Its specific gravity is about 10, and its melting point about 2500 degrees Cent. The metal is used for electrical contacts, filament supporters in electrical lamps, for winding the heating coils in resistance furnaces, and in the chemical industries; its main use, however, is in the manufacture of alloy steels—alone, or with chromium, manganese, nickel, cobalt, tungsten, and vanadium. In 1904 J. M. Gledhill found that the addition of a small amount of molybdenum to an ordinary tungsten high-speed tool steel increased its cutting qualities. However, the use of molybdenum was not much favored until tests were made which showed that, where conditions called for hardening, the addition of molybdenum up to two

per cent was beneficial; but that increases over this figure were detrimental. The action of molybdenum was found to be similar to that of tungsten, but the former is more active than the latter, and only about one third is necessary to obtain the same result. The method of manufacturing molybdenum steels is by the crucible process, but they can be made in the electric furnace. The molybdenum is usually added either as the powder, or as ferromolybdenum. Some of the alloys are chromium-molybdenum, tungsten, and nickel-molybdenum. These now have a wide range of uses: structural steel, motor car frames, crankshafts, propellor shafts, high-speed tools, etc.

RESEARCH IN METAL CUTTING. By O. W. Boston, professor of shop practice and director of the department of engineering shops, University of Michigan, in *American Machinist*, November 19, 1925, page 805.

The author maintains that in this research the aim should be the discovery of fundamental facts, rather than an investigation dealing only with practical results. He states that during the last two years an investigation has been conducted in the machine tool laboratory of the University of Michigan on elementary principles involved in the cutting of metals, a work proposed by the Manufacturing Methods Committee of the Michigan Manufacturers' Association and supported financially by the industries of the state. The problems undertaken were, to determine: the influence of the degree of sharpness of the tool on the energy required to remove a given volume of metal, the influence of the clearance back of the cutting edge of the tool, on the energy required to remove a given volume of metal, the influence of the front rake of the tool on the energy required to remove a given volume of metal, the influence of side rake (skew) on the energy required to remove a given volume of metal, the influence of the depth of cut or width of cut, on the energy required to remove a given volume of metal. There are illustrations of the tools used for the various investigations, and of a dynamometer mounted on a Liberty planer. The experiments have been concluded, and the data are being summarized and interpreted in the form of a final report.

MAKING MACHINE-TOOLS SAFE. By R. F. Thalner, safety director, Buick Motor Co., Flint, Mich., in *Journal* of the Society of Automotive Engineers, November, 1925, page 479.

The author outlines previous and present practice in the prevention of accidents, states the governing factors of accident-prevention progress and suggests possibilities of improvement of methods and the means for applying them, referring specifically to machine tools. He maintains that forethought exercised in the design of tools to make them safe as well as suited to the work is the best method, and redesign is practised when hazards become apparent after a tool is put into operation. If redesigning a tool does not make it safe to operate, the next best method is to guard it. The following rules governing the safe operation of tools are given: Men who operate vertical drilling-machines should never wear gloves or long sleeves. Milling-cutter chips shoud be brushed aside only with a brush or with a stick. Belts and gears ought always to be covered to prevent the entanglement of workmen. Chips and long shavings from lathe tools can be largely eliminated by proper

grinding of the tool, and flying particles from high-speed brass-turning operations can be controlled safely by sheet-metal guards. Emphasis is centered on the statements that most accidents are caused, they do not simply "happen," and that tools which cause accidents can be made safe. Illustrations are given showing some of the dangers and the methods of guarding against them.

CHARGES CUPOLAS MECHANICALLY. By William G. Hammerstrom, in *Foundry*, November 15, 1925, page 909.

In this article the author shows how a mechanical charging equipment recently installed at the Radford, Va., works of the Lynchburg Foundry Co., Lynchburg, Va., has removed all manual labor on the charging floor, with the exception of the crane operator, thus effecting a monetary saving in addition to obliterating one of the hardest tasks in the foundry. Metal is melted in four 96-inch diameter shell cupolas lined with 8-inch deep cupola block, and back bricks from the bottom up to within 30 inches of the charging door. The cupolas are served by two positive blowers, and are used in pairs on alternate days, one pair being in operation while the other is being made ready for the following day. The charging device is an overhead crane of 30 feet span, traveling lengthways of the building on runways fastened to the columns of the steel structure. The crane makes 20 trips per hour, or one trip every third minute, to keep the charges at the proper level in the cupolas.

CLEANING CASTINGS HYDRAULICALLY PROVES ECONOMICAL. By E. C. Barringer, in *Iron Trade Review*, November 19, 1925, page 1267.

In this article the author compares the old method of cleaning castings with the method of cleaning them by hydraulic pressure. Castings are poured, are swung by a traveling crane into a concrete chamber and deposited on a turntable. A workman pushes a button and a three-section telescopic roof closes. Another button, and the doors at one end swing shut. A third button, and a 6-stage centrifugal pump unlimbers. A stream of 425 pounds pressure surges through a nozzle balanced so well that one man directs it. In an incredibly short time the casting is entirely cleaned. The savings in time and labor is great, two men doing the work of sixty in the old method. Dust and dirt have been eliminated to such an extent that the cleaning end of the main foundry building is the least dusty and most orderly portion. Castings are routed through so expeditiously there is no accumulation. There are illustrations giving plans and views of the machinery used. After six months of actual operation at the Allis-Chalmers Mfg. Co., Milwaukee, this method is declared to be a complete success.

BAD CASTINGS AND FURNACE SCRAP. By H. H. Hopkins, in *Iron Age*, November 5, 1925, page 1252.

The fact that a number of merchant furnaces use scrap in their mixture and try to conceal this practice from the trade brings up the question whether the use of pig iron, made partly with scrap, results in defective castings. Some practical results are noted and some errors in reasoning pointed out in this article. It can be proved that defective castings were made before anyone had thought of using scrap, and that companies which use scrap in their castings have no complaints that could be attributed to the use of scrap. Evils attributed to the use of scrap are, therefore, probably overrated.

ELECTRIC FURNACE STEEL

(Discussion Continued from Page 781)

to conceive that water vapor, possibly from moisture on the scrap, could exist even long enough to be dissociated by the arc. Of course there is air present in the furnace when melting is started. Melting generally takes place gradually, from the bottom upwards. In this case it is also hard to conceive how nitrogen could be taken up by the metal. After the slag is formed it should protect the metal effectually from the action of air. In addition there is ordinarily a gas pressure in the furnace which prevents any air from entering except when the doors are open wide. The possibility of nitrogen and hydrogen being present is an interesting one and will bear further investigating.

Mr. McKnight mentions an instance of blowy steel resulting from melting high silicon crop-ends and mill scrap under a deoxidizing slag. It has been the writer's experience that in melting without oxidation (the so-called white slag melt down) the silicon is almost completely oxidized and removed permanently from the bath. There is always some rust and scale on the scrap and as silicon is the first element to be oxidized it is practically impossible to prevent it from being at least partially removed. In checking over the log sheets of a number of heats melted without oxidation and on which complete analysis records were available, the silicon content immediately after melting was less than 0.050 per cent in every case, even though the average percentage in the scrap was 0.250 per cent. Until reading Mr. McKnight's statement the writer has considered it almost an impossibility to melt down high in silicon, although in the case of steel containing up to 1.00 per cent silicon, with which the writer has had limited experience, we see how it could be possible. The experience of Mr. McKnight in melting high silicon steels lends proof to the theory that silicon affects the solubility of gas.

In the paper on electric steel the so-called final deoxidizers were not discussed. In general, the use of aluminum and other final deoxidizers is not looked upon with favor in electric steel melting. The reason for this is found in its efficiency as a deoxidizer and degasifier. This statement may seem paradoxical and in one sense it is, but as soon as the furnaceman discovers that a few sticks of aluminum will quiet the wildest heat, making it pour beautifully, he is at once inclined to become careless in working his heat because he knows he can cover up his bad furnace practice by using aluminum at the end. This will continue until the steel becomes inherently poor and badly contaminated with inclusions of alumina. A little aluminum used judiciously is an excellent thing, but it is almost an impossibility in the average shop to be sure that it is used judiciously; hence its use is often forbidden.

Reviews of Recent Patents

By
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Member of A. S. S. T.

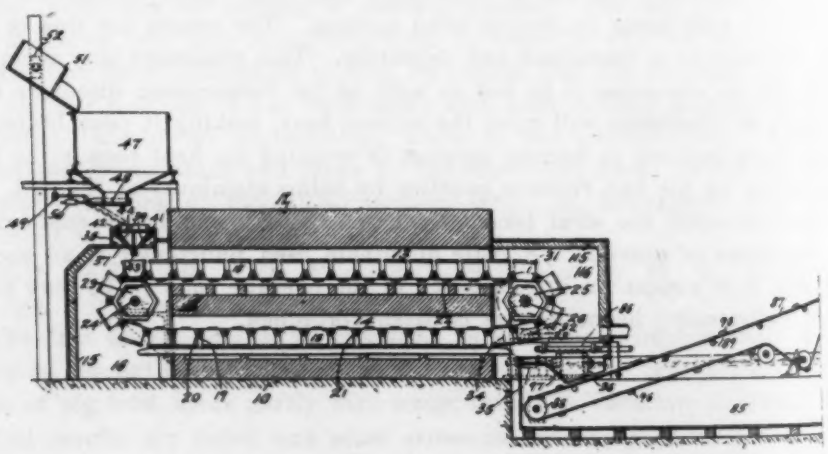
1,553,758, Core for Steel Castings, Carl Fr. Eckert, of Saarbruck, Germany, assignor to Eckert, Oppelt & Cie, Gesellschaft mit beschränkter Haftung, of Saarbruck, Germany, a firm.

This patent relates to a core for steel and other castings, which comprises an outer layer or perhaps an entire core formed of aluminum-nitride, together with the customary binding agents, such as molasses, tar, and the like. Owing to its high refractoriness, aluminum-nitride, as a core material, does not burn to the casting, and after the burning out of the binding material, does not cake so that it can be easily removed from the casting and no difficult cleaning of the casting is necessary.

1,554,241, Plant for Treating Metal Articles, David L. Summey, of Waterbury, Connecticut, assignor to Scovill Manufacturing Company, of Waterbury, Connecticut, a corporation of Connecticut.

This patent describes a plant for automatically heat treating metal articles of various kinds, more particularly for treating drawn brass shells or cups.

The apparatus comprises a furnace 12 having an upper heating chamber 13 and a lower return chamber 14. A bucket chain 18 travels through the chambers 13 and 14 and over the hexagonal pulleys 23 and 24 at each end of the chamber. At one end of the furnace a charging



hood 15 is provided, into which the articles to be treated are received from the hopper 47 and deposited in the buckets 18, which travel through the upper heated chamber 13 at a predetermined speed in order to effect

the desired heat treatment. At the opposite end of the furnace chamber is a discharging hood 115 from which the articles in the buckets 18 are dropped into a quenching liquid in the tank 85. From the tank 85 a belt conveyor 87 conveys the quenched articles into a rotating drum, in which they are automatically subjected to the action of a pickling liquor, a washing liquor, a soda solution and a soap solution, and then discharged from the treating apparatus.

1,555,798, Metal Pickling, James H. Gravell, of Elkins Park, Pennsylvania.

This patent describes a material for neutralizing the acids used in the pickling of steel and iron, comprising sodium silicate, one gallon, to seven gallons of water. The sodium silicate solution is used in place of the ordinary lime water to neutralize the acid, and forms on the iron insoluble silicates which do not rust, and also forms a coating which protects the metal against rusting influences. If desired, a particular color may be applied to the solution by using suitable pigments for that purpose.

1,555,400, Heat Treating of Metal, John E. Burns, of Indianapolis, Indiana.

This patent describes a fused salt bath for use as a heating bath in heat treating metals or the like.

The preferred mixture comprises 75 per cent of sodium nitrate and 25 per cent of potassium nitrate. This mixture can be maintained in a molten state from 400 degrees Fahr. to about 1000 degrees Fahr. The wide range of temperature permissible with the mixture, permits the various heating effects to be secured, and any salt adhering to the metal is quickly removed in the quenching operation.

1,556,347, Carburizing Material, George W. Pressell, of Philadelphia, Pennsylvania, assignor to E. F. Houghton & Company, of Philadelphia, Pennsylvania, a corporation of Pennsylvania.

This patent describes a carburizing material of high carburizing value, which may be used as an energizer for inert substances as an accelerator for intensifying the actions of materials which, in themselves, possess case hardening properties.

The new material is formed by treating 42 parts and iron oxide containing iron equivalent to 2 per cent of the charge of sodium carbonate, 56 parts of coke at approximately red heat, with nitrogen, forming a mixture comprising sodium cyanide, sodium carbonate, sodium ferrocyanide, sodium silicate, iron and alumina, calcium carbonate, carbon, and moisture. This material is in granular form and retains its granular form when used for carburizing purposes. As an energizer for inert or partially active materials, it may be applied by merely blending the material with the inert packing material. The carburizing composition has a long life, and in some instances appears to regenerate its activating properties.

News of the Chapters

STANDING OF THE CHAPTERS

IN the November issue of TRANSACTIONS appeared the relative membership standing of the 29 chapters of the Society as of September 1, 1925, and as of October 1, 1925. The tabulation which appears below shows the relative membership standing of the chapters on October 1, 1925, and November 1, 1925.

Standing as of November 1, 1925

GROUP I	GROUP II	GROUP III
1. Detroit (388)	1. Hartford (123)	1. Tri City (65)
2. Cleveland (373)	2. Lehigh Valley (107)	2. Rochester (59)
3. Pittsburgh (307)	3. Golden Gate (93)	3. Los Angeles (59)
4. Chicago (276)	4. Syracuse (80)	4. New Haven (53)
5. Philadelphia (256)	5. Milwaukee (80)	5. Worcester (51)
6. Boston (223)	6. Cincinnati (75)	6. Schenectady (50)
7. New York (220)	7. St. Louis	7. Washington (50)
	8. Indianapolis	8. Rockford (48)
	9. Buffalo	9. Toronto
	10. North West	10. Providence
		11. Springfield
		12. South Bend

Standing as of October 1, 1925

GROUP I	GROUP II	GROUP III
1. Detroit (380)	1. Hartford (123)	1. Tri City (66)
2. Cleveland (360).	2. Lehigh Valley (104)	2. Rochester (60)
3. Pittsburgh (301)	3. Golden Gate (94)	3. Los Angeles (59)
4. Chicago (267)	4. Syracuse (80)	4. New Haven (54)
5. Philadelphia (252)	5. Cincinnati (76)	5. Schenectady (50)
6. Boston (219)	6. Milwaukee (75)	6. Washington (49)
7. New York (212)	7. St. Louis (63)	7. Worcester (48)
	8. Indianapolis	8. Rockford
	9. Buffalo	9. Providence
	10. North West	10. Toronto
		11. Springfield
		12. South Bend

On date of November 1, 1925, there were in the society 3,516 members and last month there were 3,452, a net gain of 64 members for the month. There was a loss of 16, dropped for non-payment of dues and 16 resignations, making a total loss of 32. Ninety-six new applications were received during the month.

The chapters showing the most new members were Cleveland 16, Detroit 10, Boston 9, Chicago 8, Milwaukee 7 and New York, Pittsburgh and Rockford with 6 each.

Group I—Detroit still leads this group with 15 members more than Cleveland. A number of applications were received for billing which will make a noticeable increase in the number of members in Group I.

It is interesting to note, however, that every chapter in this group showed an increase in membership for the month.

Group II—A noticeable change in this group is the advance of Milwaukee from 6th place in the previous report to the 5th place in this report with a lead of 5 members over Cincinnati and tying with Syracuse for 4th place. It will be well, however, for chapters 1, 2 and 3 in this group to observe Syracuse for the next two or three months.

Group III—The noticeable change in Group III is the advance of Worcester from 7th place to 5th, passing both Schenectady and Washington who are tied with 50 members each. Practically all of the chapters in the third group have membership campaigns well planned and it will be interesting to note the progress from now on.

There has been a net gain of 156 new members in the two months since the close of the membership year, August 31, 1925.

BOSTON CHAPTER

On Friday, November 6, 1925, about one hundred members and guests of the Boston Chapter gathered at the Walker Memorial, of Massachusetts Institute of Technology to hear a talk by Henry J. Voltmann, of the W. S. Rockwell Company, New York,—who selected as his subject "Heat Application and Furnaces in General."

Mr. Voltmann gave a complete talk on the design and operation of heat treating furnaces and showed a large number of illustrations of furnace installations with which he was familiar. He described several types, including stationary, car type, semi and wholly automatic furnaces, giving in detail the class of work to which each type was best adapted.

After the half hour's discussion which followed Mr. Voltmann's talk, J. L. Faden, of the Boston Chapter, told of his recent trip to the River Rouge Plant of the Ford Motor Company, during which he had the opportunity of seeing the extensive electrical heat treating and the experimental electric forging installations of that company.

Prior to the meeting, dinner was served in the grill room of the Walker Memorial to sixty-seven members of the Chapter. The meeting was presided over by the chairman, Jesse M. Darke, and the program of the evening was under the general direction of H. B. Briggs, of the Program Committee.

The Chapter is looking forward to the December meeting when Dr. Albert Sauveur, Professor of Metallurgy at Harvard University, and an honorary member of the American Society for Steel Treating, will give a non-technical talk on the "Directional Properties of Steel." Dr. Sauveur will discuss the advantage of physical properties of steel in transverse and longitudinal directions and the reasons for this effect. His talk, which will be illustrated, will

be of equal interest to the practical heat treater and to those especially interested in metallography.

As usual, an informal dinner will precede the meeting.

E. H. Handy.

BUFFALO CHAPTER

The October meeting of the Buffalo Chapter was held on the 22nd, and was called to order at 8:15 p. m. by Chairman, Mr. Armstrong, who introduced W. S. Bidle, president of the Society.

Mr. Bidle gave a short history of the Society and what the Winter Sectional Meeting would mean to Buffalo.

Mr. Bidle also gave a talk on experiences in heat treating, which experiences were gained through practice and traveling. A number of different heat treating plants were described.

Interesting discussions followed. About fifty-five members and guests attended the meeting.

At 6:30 the Executive Committee had dinner with Mr. Bidle.

CHICAGO CHAPTER

One of the most successful meetings for some time, both from the point of attendance and program, was that of the Thanksgiving Season held Thursday, November 12, at the City Club.

Around hundred sat down to dinner at 6:15 o'clock and by the time Mr. Nelson, associated with Hart, Shaffner, and Marx, began his extremely interesting histology of cloths and clothes, probably 150 men filled the dining room and overflowed into the balcony on the east. This coffee talk was just another example of what there is to be known and admired and emulated of professions and industries entirely extraneous to iron and steel, the industry in this case ranking seventh among the great industries of the United States and being one that is vital to every one who must clothe his person either for protection or ornamentation.

You would have marveled at the origin of cloth patterns, some of which are copied from old Peruvian pottery, and others reproduced from fragments of antique blankets loaned the manufacturers by museums. You would have taken pleasure in following the sine curve of the evolution of clothes always alternating between the two extreme demands, protection and ornamentation, and finally coming down to present day clothes which Mr. Nelson tells us are swinging strongly toward the extreme of ornamentation. Then there was the matter of who sets the styles, the place of the artist in tailoring, the psychology of advertising, and the growth of the business from the old hand-me-down trade, which recorded business failures up to 94 per cent, to the present day scientifically manufactured custom built clothes. When he was all through one wondered that one knew so little of such a vital thing as the clothes we have to wear every day.

We find these short coffee talks help a great deal in clearing the atmosphere and freshening the minds of the members so that the speaker of the evening to follow is not handicapped from the beginning by a stale audience. It tends to make the listener more alert and sympathetic instead of being as usual more or less hypercritical when steel is the topic.

At any rate J. M. Watson, metallurgical engineer of the Hupp Motor Car Corporation, Detroit, found an extremely attentive audience when he came to talk on the Heat Treatment of Automobile Parts. His lecture was given in connection with several reels of motion pictures prepared by the Bureau of Mines in cooperation with the Hupp Motor Car Corporation, illustrating the heat treating processes as carried out by that corporation under the direction of Mr. Watson. In filming these processes of heat treatment as applied to automobile parts, attention was directed to the matter of automatic furnace control and operation, automatic quenching, study of microstructure as a guide to proper operation, the necessity of normalization to obtain uniform results in production work, and the matter of careful inspection of all high duty parts. The explanatory remarks coming from Mr. Watson himself made the film doubly instructive. Immediately after Mr. Watson had finished, the meeting was thrown open to discussion and the speaker was called upon to go more into detail regarding operations and experiences.

Being introduced by the chairman as a man who, even if he had no metallurgy to give his company, would be invaluable to them merely by reason of his personality, Mr. Watson more than bore out such a regard and the chapter is deeply grateful to him.

It might be added here that Mr. Watson brought with him sincere congratulations both from the Detroit Chapter and himself, personally, on the occasion of A. G. Henry being made a Founder Member of the Society and R. G. Guthrie being nominated a member of the Board of Directors.

J. A. C.

CINCINNATI CHAPTER

Meeting: Thursday, November 12, Ohio Mechanics Institute.

Subject: Die Castings—Sam Tour, Doehler Die Castings Co., Batavia, N. Y.

No report of this meeting received.

CLEVELAND CHAPTER

E. C. Bain of the Union Carbide and Carbon Research Laboratories, Long Island City, N. Y., was the speaker at the November meeting of Cleveland Chapter, held at the rooms of the Cleveland Engineering Society, Hotel Winton, on Friday evening, November 20.

With the aid of a number of excellent lantern slides, Mr. Bain explained the method of crystal analysis by the diffraction of X-rays. Giving first an exposition of the elementary principles involved, he showed how the X-rays are produced, and how they are employed to make a permanent record of the atomic structure of a crystalline substance.

Since the discovery of Von Laue that a crystal may be used as a natural diffraction grating for X-rays, other research workers have developed this idea into methods for measuring the distances between the different layers of atoms in the crystal, and for determining the arrangement of the atoms.

The experimental method of Hull, and the application of this X-ray crystal analysis to the study of metallic alloys, especially steel, were described and illustrated by diagrams. A detailed explanation was given to show how

the various crystal forms, such as "face-centered cubic," "body-centered cubic," etc., could be distinguished.

Photographs of the apparatus used in making the films were shown, and a number of typical photographic records of iron-carbon alloys were exhibited.

In concluding, Mr. Bain discussed one of the most recent applications of this X-ray work, the identification of austenite and martensite in samples of steel subjected to certain heat treatments.

Mr. Bain, as is well known, has done advanced work in this field, and his lecture was of unusual interest. He handled his somewhat difficult subject in a way that held its audience attentive for more than an hour.

A number of steel treaters were present at the dinner which preceded the meeting.

A. S. Townsend.

DETROIT CHAPTER

The Detroit Chapter of the American Society for Steel Treating held their regular monthly meeting, November 16, at the General Motors Building. The usual dinner at 6:30 p. m. preceded the meeting.

This month our coffee talk was given by the Michigan Bell Telephone Company. Their program consisted of a demonstration, by means of a miniature switch-board, of how a telephone call is made, using a manual phone. The machine switching type was also explained, step by step. The method of connecting a manual to a machine switching telephone and vice versa, was given. As a conclusion a little comedy was put on illustrating how telephones are used and then how the company would like them used.

The talk of the evening was given by M. A. Grossmann on "Precautions in the Manufacture of Alloy Steel." Mr. Grossmann started with the raw materials, as steel scrap, explaining effect of size of pieces on resultant product. The smaller the pieces the greater the amount of oxides introduced into the bath and hence the greater chance for blow holes, gases other than oxygen and wild steel.

Commenting on crucible practice, Mr. Grossmann informed us that the carbon content from crucible to crucible might vary from 0.50 to 0.86 per cent due to graphite from the crucible supplying carbon. Due to this fact, it is American practice to pour several crucibles into one ladle, and then into ingots. This procedure, of course, exposes the steel twice to the effects of the oxygen of the air while molten.

After showing several slides of the processes, Mr. Grossmann told of molds and surface imperfections resulting from molds. These are mitigated to some extent by mold coatings.

The subject of pipes and segregations was touched on in general. The use of hot tops and different types of hot tops were illustrated.

Ingot cracks were discussed in some detail. The usual causes are:

(1) Steel pressure in mold.

(2) Hanger cracks, caused by steel overflow on top of mold solidifying and failing to support ingot.

(3) Internal shrinkage cracks.

Practical methods to overcome these were mentioned.

After the steel has been stripped of the mold, illustrations were shown of

rolling mills. Cracks caused by excessive work in the mill were described. The removing of cracks by chipping and grinding was considered and then the final annealing of tool steels before leaving mill was shown.

After the paper, Mr. Grossmann was questioned by a number of members. Great interest being developed in normal and abnormal steels.

Mr. Grossmann's paper will be published in TRANSACTIONS.

E. P. Zimmerli.

GOLDEN GATE CHAPTER

The November meeting of the Golden Gate Chapter was a most successful affair. It was held November 11 at the Whitecotton Hotel, Berkeley, there being forty-nine present for dinner and a total of seventy at the meeting following.

In the absence of the chairman, Frank B. Blake, Fred L. Wight, of the Executive Committee, presided. The meeting was called to order unusually early, at 7:40 p. m.

The roll call was followed by the report of C. S. Moody, chairman of the committee in charge of the course on metallurgy. He gave a description of the plans for a nineteen week course, consisting as much as possible of actual shop and laboratory work in heat treating and metallography, and said that a printed announcement would soon be mailed to all members.

The secretary then made his report, announcing that through the courtesy of the Interstate Iron & Steel Company of Chicago, a supply had been received of their valuable Alloy Steel Handbook, edition of 1925, sufficient to furnish one for each member, and that they would shortly be placed in the mail.

Mr. Garlinger and Mr. Coulter of the Membership Committee made some remarks on the work they had been doing and on the general benefits obtained by membership, both educational and otherwise.

The chairman then called on the first speaker of the evening, A. N. Armitage, metallurgist, Columbia Steel Corporation, who presented a carefully thought out paper on annealing, with particular reference to steel castings and forgings. Mr. Armitage's wide experience enabled him to amplify his talk with a number of concrete examples of procedure, as well as microscopic photographs of samples. The talk was followed by a spirited discussion.

The chairman then introduced the speaker of the evening, J. H. Wilson, general manager of the Pacific Sheet Steel Corporation. With the general subject of "Annealing," Mr. Wilson described in detail the subject of handling of sheets of the several best known varieties. Beginning with the general definitions, he passed into a brief description of the method of manufacture of sheet steel, and finally to the subjects of annealing and normalizing, with particular reference to the box anneal. Mr. Wilson then described the various types of sheet manufacture and the problems met with in the work. He also described the process of annealing in continuous furnaces, the manufacture of strip steel, etc. He closed with the presentation of a number of photomicrographs of various samples taken at different periods of manufacture and with curves showing the relation of temperature between the inside and the outside of the box in annealing.

The discussion that followed kept Mr. Wilson on his feet for nearly half an hour, answering questions and amplifying his previous words.

The success of the evening was indicated by the large number of men who stood in groups discussing the remarks of the two speakers, for half an hour after the meeting was formally adjourned. *D. Hanson Grubb.*

HARTFORD CHAPTER

The regular meeting of the Hartford Chapter was held November 10, 1925, at the rooms of the Hartford Engineers' Club, and had a large attendance. The speaker of the evening was Hugh Rodman of the Rodman Chemical Company, who chose as his subject "The Manufacture of Carburizing Compounds." The paper was divided into two parts, the first dealing with the materials entering into carburizing materials, particularly energizers, the second dealing with the actual manufacture of the compounds. Mr. Rodman gave a very interesting discussion of the properties of compounds using the various alkalies and alkali earths as energizers, showing how these properties varied in accordance with the atomic weight of the energizer. He also gave proof that the carbon absorbed by the steel came from the carbonaceous material of the compound, and not from the alkali carbonate, so that the latter was acting simply as a catalyst.

Mr. Rodman then gave a detailed description of the various processes entering into the manufacture of commercial carburizing compounds and a discussion by several members followed.

The Chapter was also fortunate in having present our National President W. S. Bidle and Secretary W. H. Eisenman, who were in Hartford making preliminary arrangements for the spring sectional meeting, which will be held in Hartford the latter part of May, 1926. Both responded to short talks, and "Bill" Eisenman gave some very instructive and timely remarks on "Selling the Metallurgical Department" which were quite different from his previous talks.

INDIANAPOLIS CHAPTER

On Monday evening, November 9, more than one hundred members and guests visited the Y. M. C. A. auditorium to attend the second Fall meeting of the local chapter and to enjoy the good fellowship of men from the various industries. The customary chicken dinner was served thus placing all in good humor for the address of the evening which was ably delivered by G. A. Richardson, manager of the technical publicity department of the Bethlehem Steel Company.

Mr. Richardson's address which was illustrated in every detail by several reels of moving pictures served to give even the man who had never been in a steel plant a wonderful idea of the gigantic industry which has been created by the ever-increasing demand for steel. Starting from the ore fields, the various processes were traced through to the finished product. Special stress was laid on the special machinery which is necessitated for producing steel at the least possible cost, consistent with quality.

A short business session was held during which arrangements were made to further broaden the activities of the chapter and to enable the members to obtain as much information as possible regarding the handling of steel. Toward this end several committees were appointed by William Praed, chair-

man and the following men will serve as chairmen of the respective committees: William Appel, library; C. B. Edwards, membership; W. R. Chapin, program, and John Nelson, publicity.

Frank Thompson, purchasing agent of the Link Belt Company, gave a short impromptu talk on economic conditions in the steel industry. Professor John Keller of Purdue University also gave a short talk on the "Why" of the steel treater and cited the wonderful influence and development of The American Society for Steel Treating. The meeting was well attended by members from near-by towns and cities. *C. H. Beach.*

LEHIGH VALLEY CHAPTER

Meeting: Friday, November 27, Drown Hall, Lehigh University, Bethlehem, Pa.

Subject: Giant Power—Samuel S. Wyer and R. A. Philip.

Meeting will be reported in next issue of TRANSACTIONS.

LOS ANGELES CHAPTER

The last regular meeting of the Los Angeles Chapter was held October 7, 1925, in the banquet room of the Los Angeles Creamery Company, there being 50 members present.

After a very enjoyable dinner and entertainment the meeting was then called to order. James Borton, of the Jamison Steel Company, was the speaker of the evening, his subject being, "The Manufacture, Use and Types of Spring Steel," and was given in a very entertaining manner. Many of the members related experiences they had had in the handling of spring steel.

Mr. Letellier, of the Union Drawn Steel Company, was then introduced and spoke to the members on a subject which proved to be very interesting, the "Manufacture of Cold Drawn Steels." Mr. Letellier answered in a very able manner many questions on the subject, and after a lively discussion the meeting adjourned. *E. C. Black.*

NEW HAVEN CHAPTER

Meeting: Friday, November 20, Winchester Club House.

Subject: Acetylene Welding—G. E. Harcke, chief instructor, Auco-Davis-Bourneville Welding Institute. Oxygen—The Wonder Worker, a four-reel film, presented.

No report of this meeting received.

NEW YORK CHAPTER

The regular monthly meeting of the New York Chapter was held in the Woolworth Building, October 21. The speaker of the evening, J. H. Critchett of the Union Carbide and Carbon Corporation, presented an excellent address entitled, "The Manufacture of Ferro Alloys and their Applications." The speaker gave a historical outline of the process tracing its origin to the early 90's when the demand for ferro alloys for use in Mushet steel, open hearth steel, and steel armament was satisfied by the carbide furnaceman. The speaker ably described the electric furnace which is the back-bone of the ferro

alloy industry and without which a large number of ferro alloys could not be economically produced. The two types of electric furnace smelting used for making high and low carbon ferro alloys were described, high carbon ferro alloys being made in a carbon-lined furnace using the submerged electrode type of smelting and low carbon alloys made in a magnesite lined furnace with open arc type of smelting. The production of 50 per cent ferrosilicon was described in detail as an example of submerged electrode type smelting. Steel scrap is melted and a mixture of charcoal, coke and quartzite rock is fed in around the electrode by machine or hand, the following reaction taking place:

$$SiO_2 + 2\ C = 2\ CO + Si \text{ and } Si + Fe = FeSi$$

Tapping is accomplished by using an auxiliary electrode to burn out the tap hole. The melt runs out of the furnace into blocks or chills which are broken up and shipped. Little slag is formed during this operation and therefore care is exercised in the selection of raw materials, only the best being used.

In early European practice selection of raw materials was not so carefully made and ferrosilicon shipped in boats on becoming damp generated phosphene with disastrous results, but there have been no such occurrences in this country. Ferromanganese containing 80 per cent manganese and 6 per cent carbon can be made by either electric or blast furnace processes and the economics are on a par. The fact that the electric furnace uses less coke, and the recoveries from the ores are higher enables competition. The ferromanganese as made in an electric furnace, is produced by smelting manganese ore low in silicon and alumina with carbon and a flux. In tapping, a runner having a weir is used to remove the slag. High carbon ferrochromium is made by similar practice. The chromium ore is expensive, being approximately 25 per cent Cr or 50 per cent CrO_3, the balance being undesirable. The alloy, after being tapped the same as ferrosilicon, is re-tapped from a ladle to separate slag and metal. The slag is so refractory that during the World War it was used for patching open hearth furnace bottoms. The manufacture of low carbon ferro alloys such as ferrochromium, ferrotungsten, ferromolybdenum and high-priced metals is accomplished by using the open arc process in small magnesite-lined furnaces. The reducing agent used in smelting low carbon ferro alloys is carbon, silicon or aluminum, the carbon content of certain grades of the finished metal being kept below 1/10 of 1 per cent. The process produces a large amount of slag and a comparatively smaller amount of metal. Large units, using three phase current and consuming as high as 12,000 kilowatts, are used for smelting the less expensive alloys such as ferrosilicon and smaller units sometimes using as low as 400 kilowatts and often single phase are used for the higher priced special alloys. The manufacture of ferrotungsten is an expensive process due to the fact that the metal has such a high melting point that pouring is impossible, it being necessary to allow the metal to freeze in the furnace and then to tear down the furnace to remove the metal. The composition of tungsten ores varies widely, phosphorus, tin, arsenic, aluminum and other undesirables may be present. Part of these are volatilized by the high temperature and part slagged off. The production of ferromolybdenum low in sulphur from molybdenum sulphide ore is made possible by the reaction between silicon and sulphur taking place in an electric

furnace which produces a volatile sulphide, thus removing the sulphur. A chemical treatment plant is desirable and necessary to an electric furnace plant for riddance of undesirables. The classification of ferro alloys in order of tonnage produced was given as ferrosilicon, ferromanganese, ferrochromium, ferrotungsten, ferrovanadium, ferrotitanium and ferromolybdenum. The careful selection of raw materials plus the advantages of the electric furnace in procuring freedom from gases, eliminating fuel defects, producing a strong reducing action and bringing reactions to the desired end, enables the producer of the electric furnace alloys to give to the consumer a uniform production in quality and analysis.

In discussing the use of the various alloys, Mr. Critchett pointed out that the use of a 15 per cent ferrosilicon addition in an open hearth furnace insured a metal free from oxides and enables a time saving. Fifty per cent ferrosilicon is used as a ladle addition rather than 15 per cent ferrosilicon which would produce considerable cooling. The function of the silicon addition is to control the density and quality of the steel, it being considered that 0.07 to 0.08 per cent residual silicon is needed in low carbon steel of structural quality, 0.15 per cent in higher carbon products such as rails, and in the best grades of steel 0.25 per cent is necessary. Seventy-five to 90 per cent ferrosilicon alloys are used where a high percentage of silicon is desired in steel. Refined silicon containing 97 per cent silicon is intended for nonferrous alloys such as silicon-aluminum alloys containing 12 per cent silicon. The use of a 20 per cent silicon, 65 per cent manganese low carbon alloy in an open hearth furnace is advisable as in melting it forms a slag which rises readily and clears the steel of inclusions. The use of various alloys was discussed such as ferrochromium, ferrotungsten and ferromolybdenum for procuring effects on physical properties; the application of low carbon ferrochromium to stainless steel manufacture and of low carbon ferromanganese to low carbon steel production was also discussed. *W. E. Griffiths.*

NORTHWEST CHAPTER

The first meeting of this year was held Wednesday, October 28, with Chairman Wm. "Bill" Sweet presiding. The large attendance indicated that this should be a banner year for the activities of this society. The executive committee had arranged a well-balanced program for the evening.

Mr. Lanehan with his Irish bagpipe furnished the music to put everybody in a good humor. Before this it had always been the idea with most of us that the bagpipe originated in Scotland, but Pat informed us that this was all wrong and gave dates to show that the Irish had them long before the Scotch ever thought of such an instrument. Fortunately, no Scotch were present that night, so no trouble ensued.

Mr. Lilygreen of the American Hoist & Derrick Co. entertained with some stories and showed his ability is not confined to treatment of steel.

R. L. Dowdell gave a very interesting report of the Cleveland Convention. He brought out the importance of attending the A. S. S. T. conventions and urged the men to begin plans now to attend the convention at Chicago next fall.

O. W. Potter gave an outline of a paper presented by him at the fall

convention of the American Foundrymen's Association at Syracuse, New York, on The Effect of Heat Treatment on Gray Cast Iron and Semi-steel. His talk was illustrated with photomicrographs showing the effect on the cast iron with various heat treatments as well as tables showing the change in physical properties.

Dr. O. E. Harder, chairman of the program committee, announced the following tentative program for the coming year.

November. Carburizing; H. B. Knowlton.

December. Fatigue of Metals; H. F. Moore.

January. Production Methods in Heat Treating; J. E. Smith of Highland Park plant of Ford Motor Co.

February. Quality Steel Problems; D. M. Strickland.

March. Alloy Steels; Mr. Wickenden of the International Nickel Co.

April. Malleable Cast Iron; H. A. Schwartz.

May. Manganese Steel; John H. Hall.

June. To be arranged by local chapter.

Dr. Harder also gave a summary of a paper on The Dilatometric Method of Heat Treatment. This paper, of which Mr. Dowdell and Mr. Forsyth are co-authors, was presented at the convention at Cleveland. The application in industry was shown by a furnace, exhibited by the Stanley P. Rockwell Co. for the first time at the Cleveland convention, which was very similar to the furnace described in the paper.

Mr. Alexis Caswell, our secretary, who knows all the weak spots of steel treaters, had provided refreshments. This was without question one of the most popular parts of the program.

After the meeting there were informal discussions and renewing of acquaintances. The beaming countenance of H. K. Briggs was missing, but the fact that he announced his engagement about a month ago may account for his absence.

Mr. Townseld of the Milwaukee Chapter attended the meeting Wednesday night. We want to extend an invitation to all members of other chapters to attend any of the meetings if they should happen to be in the city at the time.

The November meeting of the society was held Friday evening, November 6, at which H. B. Knowlton of the Milwaukee Chapter gave a very interesting talk on The Carburizing of Steel. His presentation of the subject may be discussed under three main headings: steel that is used, carburizing compound, and some of the difficulties encountered.

The steel used should always be of a good grade as it is impossible to obtain good carburized parts if the original steel is of inferior quality. Sulphur should be kept below 0.05 per cent as it is very likely to cause soft spots or cracking in the case. Abnormal steels were also discussed and photomicrographs were shown to point out the difficulties in carburizing it. The Ehn test was recommended for routine examination of all steel stock that is to be carburized.

The carburizing compound consists of some carbonaceous material such as charcoal, bone black, coke, or charred leather, and an energizer such as barium or sodium carbonate. The effect of the energizer was shown very clearly by a series of experiments which were described.

The difficulties discussed were soft spots in the case which may be due to a banded structure in the original steel, segregations, and decarburization either in the pot or during the hardening operation. The trouble of getting different depth of cases in different carburizing boxes may be due to uneven temperature in the furnace. The use of test pins was recommended to overcome this difficulty. Chipping or cracking of the case may be due either to the heat treatment, carburizing or grinding of the steel and these were discussed fully.

After the main talk there was a good lively discussion of the paper and only the fact, that Mr. Knowlton had to catch a train, made the meeting adjourn as early as it did with many still eager to ask questions in regard to their difficulties in carburizing. *L. J. Weber.*

PHILADELPHIA CHAPTER

The second regular meeting of the Philadelphia Chapter was held at the Engineers Club October 23, preceded by the usual dinner and an excellent address by Dr. Cattell, Philadelphia's grand old man. Dr. Cattell proved conclusively that Philadelphia is the city in which to hold the 1927 Convention.

The Chapter was honored at this meeting by a visit from President Bidle, Vice-President Bird and National Secretary Eisenman.

The Philadelphia Chapter is conducting a membership campaign that has been eminently successful during the short time in which it has been under way. Two teams have been formed consisting of six men each, one team is captained by Mr. Gebert and one by Mr. Succop. The campaign is to continue for the remainder of the year, and the team securing the greater number of new members is to enjoy a dinner and theatre party at the expense of the other team.

Sam Tour of the Doehler Die Casting Company delivered a lecture on die castings, and handled the subject as only Mr. Tour can. Any chapter that is favored by a talk by Mr. Tour is indeed fortunate. *A. E. Donovan.*

PITTSBURGH CHAPTER

The November meeting of the Pittsburgh Chapter was held on the evening of the 5th in the auditorium of the U. S. Bureau of Mines Building.

Preceding the meeting, supper was served in the cafeteria of the Mines Building and while the supper was in progress, a pleasing program of dancing and singing was given by several entertainers.

A handsome fountain pen and pencil was given as a door prize for which W. J. Merten held the winning number.

Chairman O. B. McMillen called the meeting in the auditorium to order at eight o'clock.

Dr. V. N. Krivobok of the Carnegie Institute of Technology announced that Dr. Albert Sauveur would give a series of three lectures at the Institute on the evenings of November 30, December 1 and 2 to which the members of the society were invited.

W. H. Phillips of the R. D. Nuttall Co., was unanimously elected as vice-chairman of the Chapter to succeed W. J. Priestley, resigned.

After the business of the meeting was consummated, Chairman McMillen introduced the speaker of the evening, E. E. Thum of the Oxweld Acetylene Co., who chose as his subject, "Heat Treatment by the Oxygen-Acetylene Flame."

In his preliminary remarks, the speaker said that he would not recommend the use of the oxygen-acetylene flame for furnace heating as it was too hot for any refractory material with which it came in contact; nor did he advise any attempt to case-harden with it owing to the fact that acetylene (C_2H_2) was not active in its carburizing action. He recommended that acetylene should not be used at more than atmospheric pressure and temperatures.

Motion pictures were then shown of the necessary equipment and how it should be operated. Throughout the pictures, the speaker gave many suggestions for efficient handling of this equipment and also explained the precautions which should be taken.

He then gave many examples where the use of the oxygen-acetylene flame was particularly adaptable mentioning among these the small heat treatment operation such as the hardening of a few small tools when the usual heat treatment equipment was not ready for immediate use or would be too costly; the emergency work where it would soften broken taps, etc., and in various kinds of experimental work.

In describing spot annealing, he told how hardened pieces of armor plate had been spot annealed by this means so that they could be drilled.

He further explained that by proper handling of the flame, spot hardening could be attained from the self-quenching action brought about by the rapid conduction of heat from the spot, which was impinged by the flame, to the remaining cold body of metal. Other examples of the great variety of production uses of this flame were the drawing of the back part of hardened dies and the hardening of certain sections or areas of small machine parts and tools.

The hardening of the stem end of the automobile poppet valve was particularly interesting both in regard to the rapidity with which it was accomplished and to the fact that the greater part of the valve was submerged in water during the heating with the flame.

The extraordinary rate of heating caused by the intensity of the oxygen-acetylene flame was impressed upon the audience by the results of many experiments which had been conducted by the speaker.

Among the uses in non-ferrous work, this flame is used in the annealing of aluminum and in copper sheet work. An interesting comment in regard to heating aluminum was that the proper annealing temperature would be indicated when a twirled piece of paper drawn across the surface of the aluminum would leave a dark line.

In the machine shop field, the oxygen-acetylene flame is of particular advantage in annealing hard spots on castings. Then, too, it has been found to be of considerable utility in spot hardening malleable rifle receivers and plow points.

The discussion which followed this talk was interesting and showed that

it had been followed with a great deal of interest and had opened new lines for thought.

The Chapter had the pleasure of hearing from J. E. Donnellan who spoke to it concerning the progress of the work of the Recommended Practice Committee of which he is the Secretary. *H. A. Neeb, Jr.*

PROVIDENCE CHAPTER

Meeting: Friday, November 13, Rooms of Providence Engineering Society.

Subject: Impressions received in Visiting Heat Treating Plants—W. S. Bidle, national president A. S. S. T. Mr. Eisenman, national secretary of the society, also spoke.

No report of this meeting received.

ROCHESTER CHAPTER

The Rochester Chapter of the American Society for Steel Treating held its 63rd meeting Monday evening, November 9, 1925.

This Chapter was fortunate in having John Howe Hall, of the Taylor-Wharton Iron and Steel Company, as the speaker for the evening. Mr. Hall chose for his subject, "Manganese Steel." He successfully carried us through the history, uses, method of manufacture, heat treatment, analysis, etc. In conjunction with his talk, Mr. Hall showed a great number of slides, and also a moving picture which were very good. There was a good attendance both at the meeting and dinner, which preceded the meeting.

The Rochester Chapter has succeeded in obtaining one new sustaining member, the Taylor Instrument Company, of Rochester, N. Y., also three regular members. They are now planning a membership campaign during which time they expect to get not less than three more sustaining members, and ten regular members.

Watch, through the Transactions, the activities of the Rochester Chapter.

C. Wattel.

Our attention has been directed to an error which occurred in the report of the October 12 meeting of the Rochester Chapter as published in the last issue of TRANSACTIONS, page 656. The second sentence of paragraph two should read—Mr. Brearly (and not Mr. Nelson) in a joking way offered a machined bar of one of the special alloys to a friend who was engaged in the cutlery business.

ROCKFORD CHAPTER

The November meeting of the Rockford Chapter A. S. S. T. was held Wednesday evening, November 18, at the Nelson Hotel. It was preceded by the usual social meal, the meeting being called to order at 8:15 by Chairman Hillman. The formal business was quickly dispatched and the meeting turned over to Mr. Muehlemeyer, chairman of the program committee, who introduced the speaker of the evening, Prof. H. F. Moore of the University of Illinois.

Professor Moore's paper on "The Fatigue of Metals" was closely followed. His remarks concerning the scientific basis of the stress and strain

formulas used by engineers were illustrated with slides and examples. Judging from this paper, the engineer should be congratulated on his eminent success in combating so many unknown and immeasurable forces that work for the destruction of his projects.

In concluding, Professor Moore announced that Bulletin No. 152 on "Fatigue of Metals" was just off the press and could be obtained from the Director of Experimental Engineering, University of Illinois.

SCHENECTADY CHAPTER

Meeting: Tuesday, November 17, G. E. Research Laboratory Auditorium.

Subject: Permanent Magnet Steels—Dr. J. A. Mathews, vice-president, Crucible Steel Company of America, New York City.

No report of this meeting received.

SOUTH BEND CHAPTER

No report received.

SPRINGFIELD CHAPTER

The Springfield Chapter of the American Society for Steel Treating held a meeting on November 11 in the rooms of the Springfield Chamber of Commerce. W. S. Bidle, National President of the Society, and W. H. Eisenman, National Secretary of the Society, were the honor guests and the principal speakers at the meeting.

Mr. Eisenman's address dealt largely with the broad activities of the National Organization. He pointed out the financial standing of the National Society, as well as that of the local Chapters at the present time, as being excellent.

With reference to the Cleveland Exposition, he stated that it exceeded all expectations. It was far the best and the largest attended exposition in the history of the American Society for Steel Treating. The Society's Annual Convention and Exposition is now an event of national importance and no one connected in anyway with the manufacture or heat treatment of steel can afford to miss it. In many instances which came to the personal attention of Mr. Eisenman, observations by manufacturers of the various improved processes exhibited at the Exposition resulted in substantial savings to them.

In conclusion, Mr. Eisenman outlined the activity of the National Organization directed toward the improvement of the prestige of men engaged in the treatment or the testing of steel. The most important step taken by the Society in that direction is a contemplated publication of the prepared book entitled "Good Will Builder," intended for distribution among manufacturers. In this book the importance of the position of a chemist, metallurgist and a foreman of the heat treating department in a manufacturing organization is explained.

Mr. Bidle's talk was confined to his observation of various heat treatment methods and equipment in a number of automobile concerns which he had the opportunity to visit. This talk was of real practical value and was greatly appreciated by his listeners. The regular get-together dinner was served at

the Highland Hotel. P.W. Oliver, chairman of the local Chapter, presided at the meeting. *N. A. Glaskowsky.*

ST. LOUIS CHAPTER

The St. Louis Chapter held their November meeting on the evening of the 20th at the American-Annex Hotel.

The speaker of the evening was Prof. H. F. Moore, of the University of Illinois, Urbana, Illinois. Professor Moore chose as the subject of his address "What Happens When Metal Fails in Fatigue"; this was illustrated by interesting lantern slides. Our speaker has made a valuable contribution to the study of metals from his vast amount of research work on fatigue of ferrous and nonferrous metals; in this work Professor Moore has the support of the National Research Council, General Electric Co., Allis-Chalmers Mfg. Co., Western Electric Co., and others.

Perhaps more were on hand for the dinner than had ever attended before, and when the meeting began the crowd was one of our largest and most enthusiastic. After the business of the evening Professor Moore addressed the meeting. He clearly reviewed the main topics of his paper; the theory of fatigue was plainly put before the members; he touched on the false theory of crystalization. His theory was built on the action of a large number of atoms, not the unreliable data of a few. Slip was illustrated by a pack of cards; two results came from continued slip: roughening of the layers of atoms which tended to reduce the slip and fracture which developed from weak spots in the metal. If there was only slip, the metal would become tougher and more resistant to fatigue; but the phenomena of actual fracture followed the slip lines very often. Final failure generally comes through the crystals, not between them. Cold working action strengthens metal; it closes up small holes in the metal, this reduces the seats of fracture. Some metals are injured by cold working, but cold working steel seems not to have any ill effect on the resistance to fatigue. Fracture will follow the weakest constituent of the metal; in the case of ferrite and pearlite, the fracture will follow the ferrite. Discussion lasted until 11 o'clock. *Alan Jackman.*

SYRACUSE CHAPTER

The following effusion was inspired by the talk of M. A. Grossmann given before the Syracuse Chapter of the Steel Treaters on November 9 at the Onondaga Hotel.

Oxygen, Oxygen
Makes a heat of metal sick,
Causes customers to kick.

Oxygen, Oxygen
Metallurgists all must lick,
Oxygen.

Mr. Grossmann spoke on the Manufacture of Alloy Steels, showing a series of lantern slides, some of which he said were included merely as examples of

good photography—and they were good ones. The speaker discussed the important steps in alloy steel manufacture, starting with the scrap pile and finishing with the inspection of the finished bars, touching in between on oxygen in steel, hot tops for economical removal of pipe, ingot molds, burying pits, hammer cogging, rolling, chipping and grinding of billets, and annealing.

The discussion which followed the talk was mainly on the subject of oxygen in steel.

W. R. Frazer, Chairman of the Program Committee, announced that G. R. Brophy of General Electric would be the speaker at the December meeting, the subject being "Photoelastic Method for Determination of Causes of Failure in Metal Structure." In January, we will have a joint meeting with the local chapter of the American Chemical Society at which time R. S. Archer of the Aluminum Company of America will talk on Aluminum and Its Alloys.

P. Peskowitz.

TORONTO CHAPTER

No report received.

TRI-CITY CHAPTER

The November dinner meeting of the Tri-City Chapter of the American Society for Steel Treating was held Thursday evening at the Davenport Chamber of Commerce. There were fifty members and guests in attendance at this meeting.

Prof. H. B. Knowlton of the Milwaukee Vocational School, Milwaukee, Wis., addressed the chapter on the subject of "Carburizing."

Carburizing is a metallurgical process in which a case or glass-hard surface can be produced on the surface of parts by packing the soft steel parts in a carburizing compound. These compounds are made up of charcoal and chemical energizers which, when subjected to a furnace temperature of about 1600 degrees Fahr., evolve a gas known as carbon monoxide. This gas penetrates the surface of the steel parts and builds up a high carbon surface. Following this carburizing treatment, the parts are hardened by heating to a temperature of about 1550 degrees Fahr. and quenching in water or oil.

The parts so treated, therefore, have a hard surface while the interior of the parts are of soft steel.

Mr. Knowlton discussed the fundamental principles of carburizing and stressed the fact that the success of the treatment depends largely; first, upon the proper selection of steel to be used for carburizing; second, selection of proper carburizing compounds; third, proper control of temperature and time cycle in the carburizing furnace; and, fourth, heat treatment following carburizing.

Considerable carburizing is done in the factories of the Tri-Cities, and, consequently, an interesting discussion followed the address of the evening.

C. H. Burgston.

WASHINGTON CHAPTER

The Washington Chapter was entertained at its November meeting on Friday, the 20th, by W. S. Bidle, National President of the Society, and R. T. Bayless, editor of TRANSACTIONS. The Secretary, W. H. Eisenman, had

also planned to be present at this meeting but was unavoidably obliged to change his plans at the last moment. In the absence of Mr. Eisenman, which was greatly regretted by the members of the Chapter, Mr. Bidle transmitted in brief the message which the Secretary had planned to carry to the members of the Chapter. He traced the growth of the Society both technically and financially from its origin by the merger of the old American Steel Treater's Society and the Steel Treating Research Society, in 1920, to the present date. He particularly emphasized the problem of selling the work of the Society to manufacturing executives not so much from the standpoint of obtaining their memberships as of convincing them of the usefulness and value to their organization of participation in the activities of the Society by those among their employees who were directly responsible for the metallurgical practices. Mention was also made of the progress of the data sheets and of the desire for further suggestions as to subject matter for data sheets with a view ultimately to making the Hand Book an all-inclusive reference manual on the most needed metallurgical subjects.

President Bidle then proceeded with the subject matter of his own talk. During the past year or more the speaker has visited a total of twenty-seven chapters throughout the Middle West and Northeastern sections of the country, and during his visits he has arranged for inspection of somewhat over fifty plants in which heat treatment of steel was a major operation. He presented to the members of the Chapter a summary of the latest practice in this work as gathered in the course of these trips. Your correspondent unfortunately took his collegiate course in an institution in which stenography was not included in the curriculum and hence was able to collect only a small proportion of the novel improvements in heat treatment practice which were brought up for the members' attention. The ideas were truly more closely packed than the iron atoms in the gamma iron crystal lattice.

Among the points brought up by Mr. Bidle, the following few are selected as being generally representative of the trend in heat treatment practice which he observed during these many trips, which were chiefly through plants engaged in the automotive and machine tool industries. Furnace equipment being the principal tool in the heat treatment plant, the construction and operation of such equipment formed the major part of the talk.

(a) Coal is practically non-existent as a source of energy, oil, gas and electricity being the chief media for heat generation. Improvements in the use of oil have been in the direction of heavier fuel with its higher heating value, equipping the system with heating devices to maintain satisfactory fluidity without such temperature increases as would be dangerous. Improvements in the use of gas have been largely in the direction of pre-mixing of air and fuel by several types of simply controlled mixing devices. Improvements in electric heating have been principally in the direction of exposed resistance units, heavy heat insulation and automatic temperature control.

(b) A large proportion of the general tonnage of heat treated articles are handled in oil-fired furnaces, but the greatest increase in capacity in recent years has been registered by manufacturers of electric heating equipment.

(c) The advances in carburizing practice have been many. One rotary carburizing furnace, electrically heated, heavily insulated and 30-feet in

diameter showed a gross thermal efficiency of 86.6 per cent. Much use has been made of the counter-flow principle in electric and fuel-fired furnaces in which a central section is maintained at the desired operating temperature and two series of charges are fed in from opposite ends of the furnace, at each end the incoming material on one side having heat imparted to it by the outgoing charge on the other side. It was interesting to note that there are no carburized parts today on the Ford car and on the tractor made by the same manufacturer, only the wrist pins receive this treatment.

(d) The use of molten cyanide solutions as non-oxidizing salt-bath heating media is growing. It is claimed that gears heated in this manner will not pit as readily under heavy loads as will those heat treated in open furnaces of the muffle or semi-muffle types.

(e) Considerable attention was given to carburizing troubles, particularly the reaction of carburizing compounds with fire clays used for luting covers and to the flaking off of copper deposits leaving exposed surfaces where carburization will occur and naturally is not desired. The causes of these phenomena were discussed.

(f) Many miscellaneous subjects were mentioned such as the cooling of quenching media by tubular coolers equipped with baffle plates, the cooling water passing through the tubes in order to avoid clogging that frequently resulted from the circulation of oil through this part of the system. Mention was also made of many novel die-hardening and straightening methods and of the use of electric furnaces because of improved construction in the line of manufacture in machine shops. It was of interest to note that at the Ford River Rouge Plant, one thousand tons of steel parts are heat treated per day.

(g) Discussing gear hardening practice one instance was cited in which, on a production of fourteen hundred gears per day, the average loss by warpage was only six. The staggering figure of ninety-six thousand gears hardened in eighteen hours in one forty-five foot continuous furnace, was also mentioned. In this connection methods of annealing involving extremely rapid cooling over certain temperature ranges, with certain steels, was given considerable attention.

In the discussion which followed, time was devoted to questions of gear warpage as affected by the previous cycle of heat treatment and machining operations, automatic temperature control as applied not only to electric but also to fuel furnaces, the use of metallic and non-metallic recuperators and other pertinent subjects.

Subsequent to Mr. Bidle's talk, Mr. Bayless expressed his appreciation at being able to attend the meeting, and asked particularly for suggestions from the members in regard to improvements in the conduct and character of TRANSACTIONS. He also made mention of the part which had been played in the preparation of papers for the Society by various members of the Washington Chapter.

A word of greeting was extended by Mr. Greene, a visitor from the Philadelphia Chapter, with an invitation to the members of the Washington Chapter to inspect the work being done at Temple University by the Philadelphia members, along the lines of metallurgical education.

Jerome Strauss.

WORCESTER CHAPTER

Meeting: Thursday, November 19, University Club.

Subject: Metallurgical Investigations at the Arsenal—Dr. F. C. Langenberg, Watertown Arsenal, Watertown, Mass.

No report of this meeting received.

NEW MEMBERS OF THE AMERICAN SOCIETY FOR STEEL TREATING

EXPLANATION OF ABBREVIATIONS. M represents Member: A represents Associate Member: S represents Sustaining Member: J represents Junior Member: and Sb represents Subscribing Member. The figure following the letter shows the month in which the membership became effective.

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Items of Interest

BETHLEHEM Steel Corporation is distributing to its stockholders a new booklet which tells how its program of modernizing, developing and expanding its plants is being carried out. Within a few years this steel company has become the second largest producer of steel in the world. The book they are issuing gives a brief history of the corporation, the rapid growth of its business, the modernization and development of its properties, and its policy. There is a list of the products manufactured and brief descriptions, with illustrations, of its seven plants. The booklet also tells where its raw materials are obtained, describes its transportation facilities, enumerates its shipbuilding and ship repair pants, and gives a list of the different offices.

Dr. Albert Sauveur, holder of the Gordon McKay professorship in metallurgy and metallography at Harvard engineering school, was engaged by President Thomas S. Baker of Carnegie Institute of Technology, and delivered three scientific lectures at Pittsburgh on November 30, December 1 and December 2. The subjects are "Directional Properties and Dendritic Segregation in Steel," and "Hardening of Steel," two lectures being given on steel hardening. These lectures were given in the evening for the benefit of Pittsburgh scientists and steel men.

Firth-Sterling Steel Company announced November 16, 1925, that E. E. Roberts will represent their company, traveling exclusively in the western part of the state of New York. This arrangement has been made in order that the Firth-Sterling Company can give better service to their friends and customers in Buffalo and vicinity. Mr. Roberts, before taking charge of the Firth-Sterling Company's New York heat treating plant, had a long, practical experience, including the working of fine steels in automobile, railroad and machine tool shops, as well as in commercial heat treating.

The Driver-Harris Company of Harrison, N. J., has purchased the works and properties of the Electrical Alloy Company at Morristown, N. J. The Morristown plant will be operated as the Electrical Alloy Division of the Driver-Harris Company and the main executive offices and sales department will be concentrated at Harrison.

The Morristown plant has been acquired because of the increased manufacturing facilities which it will give the Driver-Harris Company. This was needed on account of the increased business which has been attracted to the company. This added productive capacity will greatly increase the company's facilities and enable it to render service and make shipments in the quantities which the trade now requires.

A much larger research and development department will be maintained

and the Driver-Harris Co. feels that by this larger department they will be able to render a distinct service to the electric heating and allied industries.

The Carborundum Company of Niagara Falls, N. Y., announces the introduction of two new products in the field of refractories. One is a new cement called "Carboplastic" cement and the other is the "Carboplastic" gun used for applying the new cement.

The principal ingredient of this new cement is Carborundum, one of the most highly refractory of all materials. By the proper selection of bonding materials "Carboplastic" cement is made to inherit the refractory properties of Carborundum and at the same time lend itself readily to application with the "Carboplastic" gun. The new cement is prepared for use simply by the addition of water to give it the proper consistency. It air sets with a strong bond and, of course, it is more resistant to high temperatures than the best grades of fire brick.

The principal uses for "Carboplastic" cement are in minimizing the serious effects on firebrick settings of localized flame impingment, of cavities due to spalling and cracking, of destructive barring off, of clinker formation and other causes for maintenance and repair. By applying "Carboplastic" cement as a coating over the firebrick face or as a plastic refractory for patching, the life of firebrick settings is materially increased and the need for frequent shut downs for repairs are eliminated. "Carboplastic" cement can be applied to either hot or cold settings.

The "Carboplastic" gun for applying this cement is one of the handiest guns of this type yet offered to industry. It is truly portable weighing but 12 pounds. It has no moving parts to get out of order and cause trouble and is operated by a single valve located close to the handle. The gun is operated by either steam or air at 100 pounds pressure. It is small, compact, easy to handle and can shoot fifty pounds of "Carboplastic" cement in less than half a minute. It sucks the cement from an ordinary pail or bucket. There is no auxiliary hopper. Complete information regarding both the new cement and the improved gun can be had by addressing The Carborundum Company, refractory division, Perth Amboy, N. J.

Volume II of Professor W. Trinks' "Industrial Furnaces" has just been announced by the publishers. This new volume, although a continuation of the first one, is complete in itself and is devoted primarily to practice. It will be found an invaluable reference to (1) men who have to decide on the type of fuel or heat energy to be used in a specific case, (2) those who select furnace equipment, (3) sales engineers of furnace equipment, (4) men who install furnaces, and (5) furnace operators.

In this volume a great deal of equipment is described, and being the only treatise in existence on the subject, this book will find a wide usage in countries other than the United States. As far as possible, fundamental types have been selected for description.

In limiting the descriptive matter to fundamental types, the author has tried to avoid too many details, as these vary constantly.

On account of the wide field covered by the subject of industrial furnaces, the author has found it necessary to supplement his own experience with that

EMPLOYMENT SERVICE BUREAU

The employment service bureau is for all members of the Society. If you wish a position, your want ad will be printed at a charge of 50c each insertion in two issues of the Transactions.

This service is also for employers, whether you are members of the Society or not. If you will notify this department of the position you have open, your ad will be published at 50c per insertion in two issues of the Transactions. Fee must accompany copy.

Important Notice

In addressing answers to advertisements on these pages, a stamped envelope containing your letter should be sent to AMERICAN SOCIETY FOR STEEL TREATING, 4600 Prospect Ave., Cleveland, O. It will be forwarded to the proper destination. It is necessary that letters should contain stamps for forwarding.

POSITIONS WANTED

CHEMIST METALLURGIST is desirous of changing positions. Has had 10 years' experience in chemical analyses, physical testing, microscopical work and heat treatment of machine tools, dies, forgings and carbonizing. Salary nominal. Prefer permanent position with future, in Cleveland district. Address 11-20.

METALLURGIST CHEMIST with 14 years' experience in the metallography, heat treating, physical testing, analysis and manufacture of the non-ferrous alloys desires position. Experience also embraces the steel industry, including alloy steels and the ferro alloys of vanadium, tungsten and molybdenum. Past 10 years employed as an executive. Desire a change for reasons over which I have no control. Address 11-35.

METALLURGIST with nine years' experience in testing, analysis, heat treatment and metallography of automotive materials, desires position with established concern. Address 11-15.

METALLOGRAPHIST-METALLURGIST desires to change position. Graduated from German University, with 3 years' experience in metallography, heat-treating, hardening and inspecting; also knowledge of physical testing. Address 11-10.

TOOL HARDENER desires position. Has had three years' experience dressing all kinds of tools for pneumatic hammers. Address 11-45.

METALLURGIST AND CHEMIST with 14 years' experience in automotive industry, desires change. Past experience includes charge of both physical and chemical laboratories and heat treating departments. Also have had some foundry experience. Location unrestricted. Address 12-25.

FORGE SHOP FOREMAN, practical and competent, desires position. Has had 22 years' experience in all kinds of hammer forging, hardening, heat treating and tool maintenance. At present employed, and reasons for change are very good. Will furnish very good references. Address 12-15.

CHEMICAL ENGINEER desires position in the plant or laboratory. Three years' experience in the chemical, physical and micro laboratory on steel and non-ferrous work. Address 12-30.

POSITIONS OPEN

WANTED: A $10,000.00 salesman to represent a prominent heat resisting alloy manufacturer in Detroit and adjacent territory. Send full information regarding present employment, experience and education. Address 11-30.

SALES REPRESENTATIVES wanted by manufacturer of industrial oil burning appliances. The line is well established and has an enviable reputation in all fields. Consideration will be given only to high grade men who have clientele among metal working industries. Give full particulars in first letter. Address 11-5.

WANTED: Three salesmen, one each for Wisconsin, Michigan and Illinois. Our product is imported Swedish iron, hot and cold rolled, and genuine Swedish tool steel. We believe the right man has a splendid future. Address 11-40.

WANTED: Hardener, primarily for hardening high speed steel. Steady work. Salary to start $140.00 per month. Answer stating qualifications and reference Pittsburgh district. Address 12-35.

WANTED: Experienced practical heat treater competent to handle entire department with capacity to heat treat upwards of 100 tons steel daily. Applicant must be experienced handling heavy work such as hammer dies, heavy alloy forgings, etc. Prefer practical man who is a student of metallurgy. State experience and education in detail, present and past positions, age, salary expected and references. Address 12-5.

WANTED: Eperienced tool steel salesman. One who knows Michigan and Northern Ohio territories. Our mill is one of the oldest and manufactures a nationally known product. Excellent opportunities for the right man. Write stating age, experience and salary desired. Address 12-20.

FOR SALE

FOR SALE—Used Brinell Machine. Write Boston Gear Works, Norfolk Downs, Mass.

FOR SALE—One Pittsburgh Instrument and Machine Company's Style "A1" Brinell testing machine in first-class condition. Address the Columbus Gear and Pump Co., 318-350 East Second Avenue, Columbus, Ohio.

FOR SALE: Exceptional Leeds & Northrup Furnaces. Guaranteed Brand New. Will sell at very great sacrifice. L & N "Hump" Heat Treating Furnace—1 No. 8058 Furnace, inside dimensions, 8½ inches in diameter and 22 inches deep. One No. 8551—F—S Recorder. L & N Drawing Furnace—1 No. 9262—24 furnace, inside dimensions, 12 inches in diameter and 24 inches deep. One No. 8970 Control Panel. One No. 8571—D—D—39 Controller. These furnaces were intended to through-harden automobile crankshafts made of ball-bearing steel which have been eliminated in the design and which has made the furnaces unnecessary. They were used only in a test, for a few hours. Address 12-10.

of others. Consequently, this volume is based not only upon the author's personal observation, but also on publications, and upon communications in which individuals and firms have stated their experience.

The book is divided into seven chapters, as follows:

1. *Fuels and Sources of Heat Energy.* Gives information concerning the cost of a given amount of heat when produced by different fuels; burning fuel economically and with the correct quantity of air.

2. *Combustion Devices and Heating Elements.* Deals with the equipment used to burn the different fuels and to convert electrical energy into heat; devices for controlling furnace temperature and atmosphere.

3. *Control of Furnace Temperature.* Devoted to the control of furnace temperature.

4. *Control of Furnace Atmosphere.* Devoted to the effects of furnace atmosphere upon the charge and the control of furnace atmosphere.

5. *Labor-Saving Appliances.* Describes and discusses in detail labor-saving devices.

6. *Critical Comparison of Fuels and of Furnace Types.* Offers a critical comparison of furnace types and of fuels (or energy supply).

7. *Selection of Fuel and Furnace to Suit Plant Conditions.* Deals with the methods which should be used in the selection of furnace types, kinds of fuel, and auxiliary equipment to suit plant conditions.

This volume is cloth-bound, 6x9 inches, and contains 405 pages and 292 figures. The price postpaid is $5.50.

R. S. Poister, metallurgical engineer of the Electro Metallurgical Sales Corporation, has been promoted from the Cleveland to the Pittsburgh office of the company to take the place of W. J. Priestley, who has been called to take charge of the New York office.

The Institute for Government Research is an association of citizens for co-operating with public officials in the scientific study of government with a view to promoting efficiency and economy in its operation and advancing the science of administration. To this end, it seeks by the thoroughgoing study and examination of the best administrative practice, to formulate those principles which lie at the basis of all sound administration, and to determine their proper adaptation to the specific needs of our public administration. The results of its studies the Institute publishes in a series of Service Monographs.

The Johns Hopkins Press of Baltimore has recently published "The Bureau of Standards," Service Monograph No. 35, by Gustavus A. Weber. The volume contains three chapters and four appendixes, as follows: first, the history of the establishment and development of the service; second, its functions, described by detailing its specific activities; third, its organization for the handling of these activities; fourth, the character of the plant; fifth, a compilation of, or reference to, the laws and regulations governing its operations; sixth, financial statements showing its appropriations, expenditures and other data for a period of years; and finally, a full bibliography of the sources of information, official and private, bearing on the service and its operations.

NEW FISHER POLISHING MACHINE

An independent unit for preparing metal surfaces with which separate heads can be used so that the same machine may be used for either fine grinding or for polishing.

The polisher consists of a vertical motor with a polishing disc directly connected to the motor shaft. Motor is mounted on a circular cast-iron base which has three (3) legs and holes for attaching to a table. Mounted on the base, and surrounding the motor, is a cylindrical nickel plated brass housing. On top of this housing is bolted a nickel plated copper bowl which completely surrounds the polishing head. This bowl is provided with a drain which draws off the polishing liquid caught in the bowl. It is also provided with a nickel plated copper cover which protects the disc from dust, when not in use.

It has a 6 inch polishing head of finished cast iron with hard rubber disc on top, for holding the polishing felt. A special counterbalanced clamping device enables the operator to quickly attach or remove the felt.

The motor can be operated on either 110 volts A.C. or D.C.; normal speed about 1700 r.p.m.

Outfit supplied with polishing head and felt disc; with cord, pendent-switch and plug. **Each, $95.00**

FISHER LEVIGATED ALUMINA

for Metallographic Polishing

This alumina is now recognized by the leading metallographists as the most satisfactory material for polishing metal surfaces for microscopical examination and photography, and is recommended in the newer text books on this subject.

FISHER ALUMINA. Grade No. 1. For all hard metals. One ounce with 50 ounces of distilled water makes the correct polishing solution. **Per ounce, $1.00**

FISHER ALUMINA. Grade No. 2. For medium hard metals. Especially suitable for cast iron, bronze, brass and all nickel and copper alloys. One ounce makes 100 ounces of correct polishing solution. **Per ounce, $1.40**

FISHER ALUMINA. Grade No. 3. For very soft metals and other metal specimens for investigation under highest possible magnifications. One ounce makes 150 ounces of correct polishing solution. **Per ounce, $1.80**

SCIENTIFIC MATERIALS COMPANY

"Everything for the Laboratory"

PITTSBURGH, PA.

The book is clothbound, 6x9 inches in size, and contains 299 pages. The price is $2.00.

A. D. Bach of the New England Metallurgical Corporation has purchased the capital stock of the company since the sudden death of W. B. Byers, its former president. The corporation will continue under the same name and will specialize in the heat treatment of all types of steel.

Mr. Bach has been engaged in the steel business, in various capacities, for the past ten years and is a graduate engineer of Lehigh University.

The Kloster Steel Corporation announces the opening of its office and warehouse at 1036 West Lake Street, Chicago, Illinois, as direct selling agent of Kloster Steel and Iron Works, Langshyttan and Stjernsund, Sweden. Complete Kloster high-grade Swedish Tool Steels, Swedish Hollow Drill Steel, and Swedish Lancashire Iron will be carried in Chicago warehouse for prompt shipments. Direct import service on steels of every description will also be maintained through this office.

Wilson-Maeulen Company, Inc., 383 Concord Ave., New York City, have recently issued an attractively printed and illustrated pamphlet (Booklet P-110) entitled "The Automatic Electric Compensator for Pyrometer Cold Junctions. This pamphlet gives a detailed description of how the automatic electric compensator improves the Wilson-Maeulen pyrometers.

Botfield Refractories Co., Philadelphia, have issued a series of folders advertising their Adamant fire brick cement for fire brick linings in oil-burning welding furnaces and gas-fired boiler furnaces. One of these folders states that a user of Adamant fire brick cement in an oil-burning welding furnace found that by the use of this cement the fire brick lasted 50 per cent longer, because Adamant produced a glaze which the welding flux would not penetrate.

The United States Civil Service Commission announces the following open competitive examination: for positions of Assistant Scientific Aid, $1,500 and Junior Scientific Aid, $1,320.

Receipt of applications for these positions will close December 26. The date for assembling of competitors will be stated on the admission cards sent applicants after the close of receipt of applications.

Full information and application blanks may be obtained from the United States Civil Service Commission, Washington, D. C., or the secretary of the board of U. S. civil-service examiners at the post office or customhouse in any city.

Effective November 10, 1925, Henry T. Chandler has been appointed assistant to the president, Vanadium Corporation of America.

Mr. Chandler has been associated with the Vanadium Corporation organization since January 1, 1923, in the capacity of metallurgical engineer, with headquarters in Detroit.

Mr. Chandler has had an extremely wide and varied experience in the

Permanent Magnet Steel

Composition is but one factor in the making of Permanent Magnet Steels. Thermal treatments before the steel goes to the customer are governing factors in obtaining proper values in finished magnets.

Simonds magnet steels are furnished in both Tungsten and Chromium grades in sheets, strips or bars. When required in the annealed condition, a special anneal is given, depending on the method of magnet manufacture. This anneal, while softening sufficiently to allow of cold working or blanking, is so regulated as to prevent loss of magnetic properties. Ordinary annealing will lower perceptibly these important values.

We maintain a magnetic testing laboratory for our own development work and to co-operate with our customers in helping them to produce a product of the highest quality. This service and our experience are available to those interested in producing high grade permanent magnets for meters, magnetos, radio work and the like.

We welcome the opportunity to improve your product, and to solve any of your present problems.

SIMONDS STEEL MILLS

LOCKPORT, N. Y.

SIMONDS

iron and steel and automotive fields, and is today one of the foremost metallurgical engineers in the country.

Prior to his coming with the Vanadium Corporation, Mr. Chandler was engaged in research and development work in the automotive field. From 1914 to 1920, he was in charge of the research laboratory of the Ford Motor Company, investigating alloy steels and their use in applied metallurgy; from 1920 to 1923, with the C. R. Wills organization as metallurgical engineer.

He received his technical education as follows: at the University of California (two years), Massachusetts Institute of Technology (three years), Sorbonne, Paris, and the Polytechnic Institute, Zurich, Switzerland (three years), in physics, chemistry and metallurgy.

While Mr. Chandler's headquarters will be continued in Detroit, he will in this broadened field have general supervision of the development and research work in iron and steel at the plants of the Vanadium Corporation of America and its subsidiary, the United States Ferro Alloys Corporation.

The Northern Engineering Works, of Detroit, Michigan, builders of Northern "Standart-ized" cranes and hoists, have recently announced a new member of their electric hoist family, known as the Northern "Standart-ized HI-LIFT".

This new hoist embodies all the essential features included in the Standart-ized five ton crane design, which has proven so successful and been one of the company's biggest sellers. The design of the hoist meets all the up-to-date features and requirements, including simplicity, accessibility, extremely high lift, a feature regarded as most essential in the present day application of electric hoists, completely enclosed gears running in lubrication, gears made of hammered steel and case hardened. The drum which is of large diameter is of the grooved type.

The hoist is provided with two brakes for holding and controlling the load, a top and bottom limit stop, roller bearings throughout. One especially outstanding feature of the construction provides that any standard make of motor can be applied.

In bringing out this new hoist the Northern Engineering Works feel that they have covered requirements which have long been demanded of hoist builders, but which have never, heretofore, been embodied in one design.

The United States Civil Service Commission announces the following open competitive examination: for the position of Junior Chemist.

Receipt of applications for junior chemist will close December 26. The date for assembling of competitors will be stated on the admission cards sent applicants after the close of receipt of applications.

The examination is to fill vacancies in the Federal classified service throughout the United States, including the Departmental Service at Washington, D. C., and the Forest Products Laboratory of the Forest Service at Madison, Wis.

Full information and application blanks may be obtained from the United States Civil Service Commission, Washington, D. C., or the secretary of the board of U. S. civil service examiners at the post office or customhouse in any city.

Transactions of American Society for Steel Treating

Vol. VIII December, 1925 No. 6

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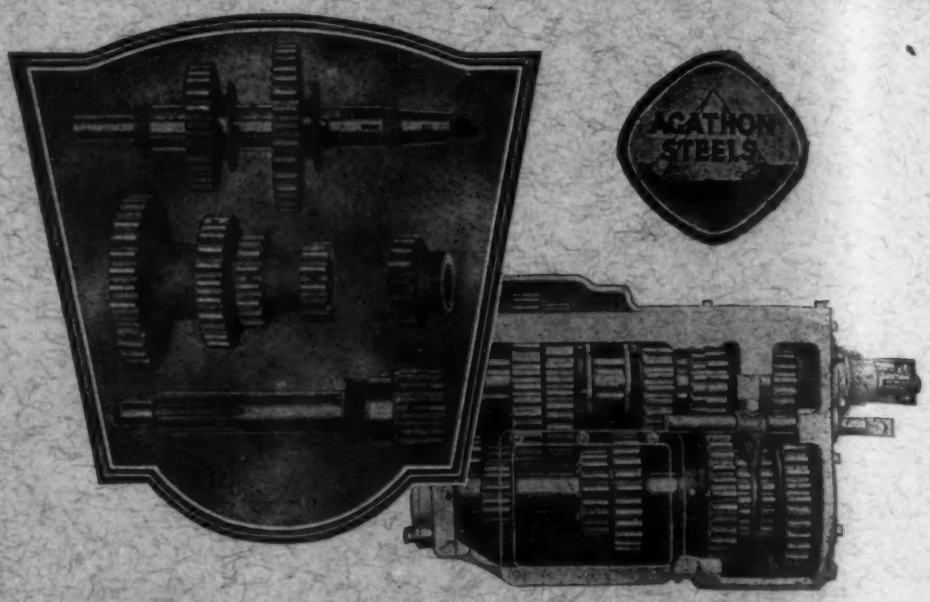

Steel for Transmission Gears

Our UMA No. 5 is a special purpose steel, designed to meet particular conditions. It is confined to a narrow range of analysis and produced with the idea of ultimate use in parts requiring a dense, uniform, hard steel.

It can be annealed in continuous furnaces of proper design, to desirable hardness and structure, in a few hours, and in batch furnaces in relatively short periods. It is, therefore, the most desirable of our UMA series for production of large quantities of automotive transmission gears.

UMA No. 5 is the most suitable of the UMA series for hard, tough service such as shear blades, hammers, dies, rolls, and all places where hard surfaces must be backed up by maximum strength and toughness.

Upon request, we will send a copy of our Agathon Alloy Steel handbook giving details and charts covering the entire series of UMA steels—made *only* by us.

We also have daily production in all kinds of Agathon Alloy Steels such as—

Nickel, Chrome-Nickel, Molybdenum, Chrome-Molybdenum, Nickel-Molybdenum, Vanadium, Chrome-Vanadium, Chromium, etc.

Deliveries in Blooms, Billets, Slabs, Hot Rolled, Heat Treated, and Cold Drawn Bars, Hot Rolled Strips, etc.

THE CENTRAL STEEL COMPANY, Massillon, Ohio

Swetland Bldg., Cleveland — Book Bldg., Detroit — Peoples Gas Bldg., Chicago
Aeolian Bldg., New York — University Block, Syracuse — Widener Bldg., Philadelphia
303 W. P. Story Bldg., Los Angeles, California

UMA-No 5
ALLOY STEEL

L&N AUTOMATIC

Potentiometer Pyrometers

Give your firemen exact operating information. Will also produce accurate records on wide (ten inch) charts.

Save fuel by knowing your temperatures exactly

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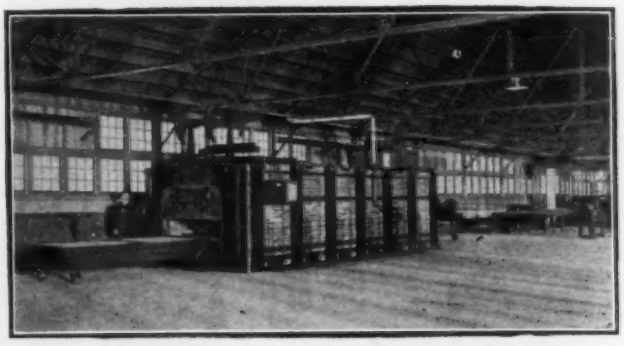
ROCKWELL

THE Need of the Moment is for Higher Quality and Lower Cost of Manufactured Products.



Single-Chamber Double-End Annealing Furnace

Improvement may be brought about by better methods of heating and handling, under the control of competent operatives or supervisors who, understanding the principles affecting the generation, application and transfer of heat, can properly employ furnaces, fuel, electricity, pyrometers, etc., as tools for the conduct of the ever-important work of "heat application."

For 35 years the Rockwell organization has devoted itself to the solution of heating and handling problems in the non-ferrous industries. Our invaluable experience and data are at your service in helping you improve the quality and lower the cost of your products.

Write for Bulletin 242-C

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FURNACES

THE

TRANSACTIONS

OF THE

AMERICAN SOCIETY FOR STEEL TREATING

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RAY T. BAYLESS, *Editor*

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Let's Cut Out

BOHNITE—Special compound that can be used over and over again, widely used by leading manufacturers.

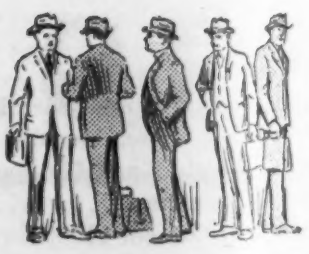
WE show in our catalog more than a dozen items of materials and equipment for the heat treating room and items similar to every one of these dozen are made by a dozen different concerns.

Think of the waste of effort, waste of time and waste of money that results from a dozen different sources of supply.

Frequent calls from the heat treating room to the purchasing department when one job is necessarily done a dozen

THE CASE SERVICE

2282 SCRANTON RD.



Delays and Waste

times—a dozen names looked up, a dozen orders dug out of the files.

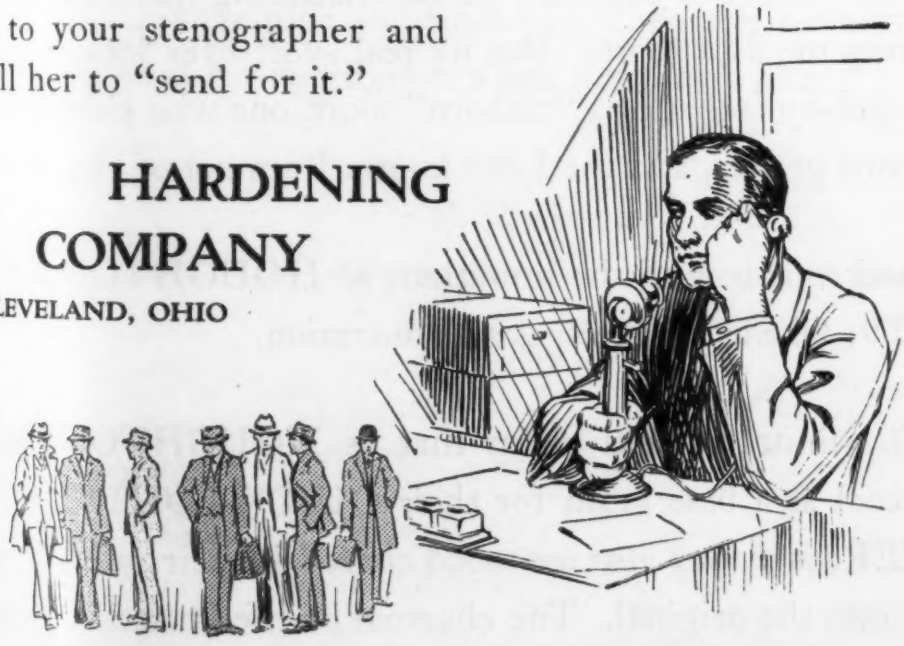
All to sell you what you can buy from us with one twelfth the effort.

Let's cut out these wastes, these delays. Send for our new catalog and get prices from us on compounds, pots and boxes, and all other heat treating needs. It is a move in the right direction. Send for it right now—tear this advertisement out and hand it to your stenographer and tell her to "send for it."

NEW BARIUM COMPOUND—We have developed a process of making barium compound that is an improvement over anything we have seen. We also make barium compound to your specifications. Write for interesting prices.

HARDENING COMPANY

CLEVELAND, OHIO



IMITATION

A SPASM

by Chas. E. Carpenter,

Near Editor

IT may be truthfully said that the above is a reproduction o photograph of myself.

The face is of me; the cap borrowed; the body and headlig on the shirt, the cane, spats and the pose, the imagination of artist who caricatured me. In other words, the cartoon is real; it is an IMITATION.

The cartoonist supposed he was flattering me. He desired portray me as a sport. But no real sport ever looked like th The get-up is that of a "tinhorn" sport, one who poses and sho his own praises, and the Lord knows I am not of that variety.

And so it is with the imitations of HOUGHTON'S PRO UCTS; take carburizers, as an illustration.

The imitators will claim that as HOUGHTON use w charcoal as a base grain for their QUICK-LIGHT* CARB RIZER, and they also use wood charcoal, their product mus like unto the original. The charcoal of the imitation product

ike unto the face in the cartoon,—the only original thing about he imitation—and even the charcoal is not of the same quality s is used in the original.

You cannot take ordinary wood charcoal and dress it up and ake it real, any more than you can take my face and dress it up nd make a real "Carps."

I am what I am when I am portrayed as I am as a whole, and QUICK-LIGHT* is what it is only as a whole.

The nicety of proportions is a qualification which is too requently overlooked by the imitators of all things. A small ortion of a poison may be most beneficial in a medicine where larger portion would be deadly.

It is never necessary to cheapen the original in order to cut rice; that is a necessity imposed upon the imitators only. In her words, "A little truth may be the greatest fallacy."

So put this in your pipe and smoke it, when you are out fish- g and want food for meditation when they don't bite.

E. F. HOUGHTON & Co.,

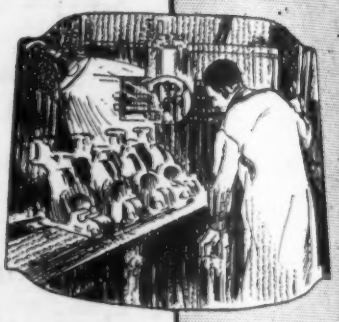
PHILADELPHIA AND ALL OVER THE WORLD

lishers—
E HOUGHTON LINE

rade Mark Reg. U. S. Pat. Off.

COLONIAL
TOOL STEELS

First— Uniformity



AS a basis, isn't it Uniformity that you want most in Tool Steel? No matter how good a certain brand may be one time, if it isn't that good every time its value to you will largely be lost. It is Uniformity that counts.

In the Colonial mill, where the entire production is concentrated on fine Tool Steels, Uniformity is the constant watchword. More than that, Uniformity is a Creed, a Creed in every step of the making.

That is why, once suited in a brand of Colonial Tool Steel, you can go on and on using and relying upon that same brand. Years will show no change. You can foretell and depend upon your results as a certainty.

It will pay you, pay you endlessly, to standardize on Colonial Tool Steels.

Colonial Steel Company

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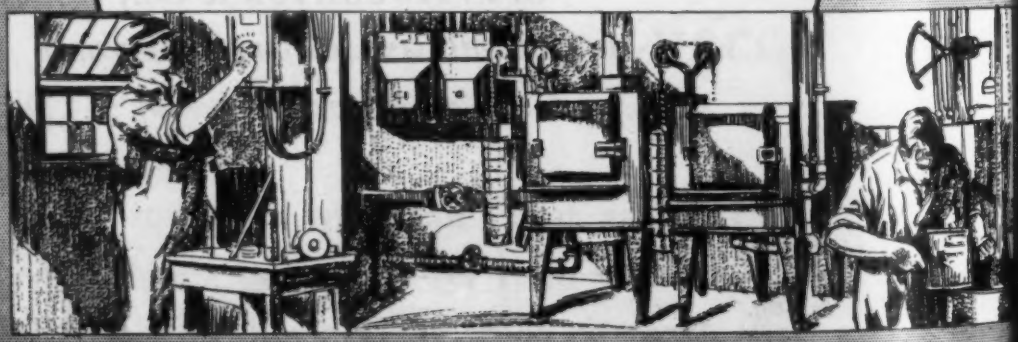
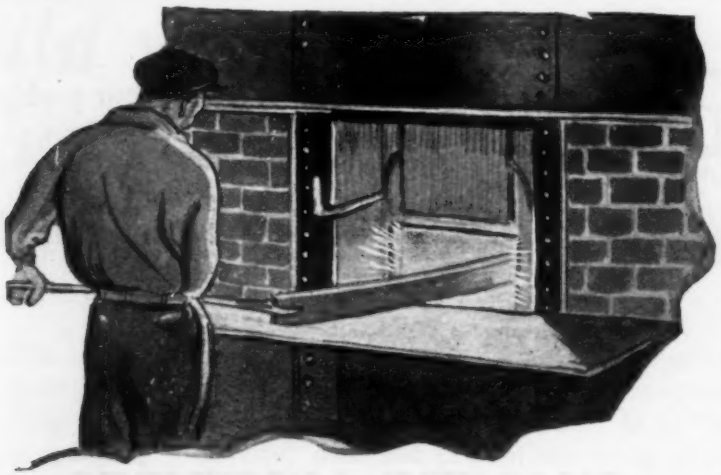
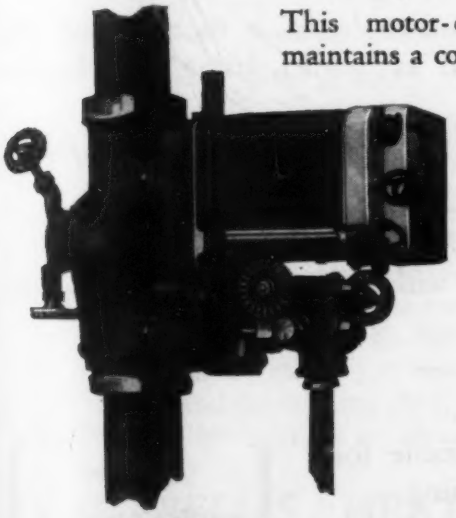
Cleveland Cincinnati Detroit Chicago St. Louis





Uniformity of Products Day after Day

The exacting demands of accuracy and uniformity of products have gradually forced the eliminaton of dependence on the human element for temperature control.



This motor-operated equipment automatically maintains a constant temperature in gas or oil-fired ovens and furnaces. It also regulates the flow of air and oil, gas, steam and other liquids. The design permits very fine adjustments.

BRISTOL'S Motor Controller Valve

has proven itself on hundreds of installations in those industries where heat treatment of metals is necessary. It is "trouble-free" and like all Bristol's Instruments thoroughly adapted to practical use. For correct mixture of air and fuel-high combustion efficiency and greater uniformity and higher quality products, investigate the Bristol Motor Controller Valve and other Bristol's apparatus.

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R&H CHEMICALS AND SERVICE

will help you solve your problems

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SURFACE HARDENING

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Choose any one of our

CYANIDE MIXTURES

(Strength 30%, 45% or 73/76% NaCN)
for the best results, your selection being
dictated by plant conditions.

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The Cheapest Method if equipped to do so, is to make up your own bath as needed, using as a basis—

CYANEGG R&H C Co TRADE MARK

CYANIDE SODIUM 96/98%

guaranteed 51/52% cyanogen
strength equal to 128/130% KCN

Dilute with Soda Ash and Salt, to suit

—▪—

Our mixtures are also highly suitable for reheating after pack hardening
Better heating medium than lead—
prevent oxidation

[*Technical assistance rendered without charge*]

The ROESSLER & HASSLACHER CHEMICAL CO.

709 SIXTH AVENUE : NEW YORK

Would you put "just a little cyanide" in your drinking water?

THEN why not be as considerate of your steel and use an ideal liquid heating medium? "Lavite" is as neutral to metals at heat treating temperatures as water is to the human anatomy. "Lavite" does not change the analysis of the metal being heat treated, nor does the Lavite bath itself change with constant use. No bath containing any cyanide can possibly have these properties, because all cyanides evolve cyanogen, leaving products that have a decided decarbonizing action on steel.

When you use "Lavite" you will forget "soft skins," surface cracks, or any periodic discarding or "rectifying" of the bath.

Other advantages from using "Lavite" are:

1. *No scaling or oxidation.*
2. *Less distortion or warpage.*
3. *Less grinding cost.*
4. *Better Production per furnace.*
5. *More uniform results.*
6. *Less heat treating cost.*

"Lavite" is supplied in grades that can be used for the heat treating of metals with temperature ranges of: 275°F —1200°F—1100°F—2000°F—2000°F—2500°F.

State kind of metal you wish to heat treat and results you desire, and we will supply the proper grade with detailed instructions for using it on your work.

THE BELLIS HEAT TREATING CO.
BRANFORD, CONN.

BELLIS LAVITE

for HARDENING, TEMPERING, HEAT TREATING

SPENCER TURBO-COMPRESSORS

GIVE

LASTING SATISFACTION

The Spencer line of Turbo-Compressors for 1 lb., 1½ lb. and 2 lb. pressures meets a wide demand for an efficient equipment of the "slow speed" turbine type for use in supplying air for oil and gas burning furnaces, foundry cupolas, etc.

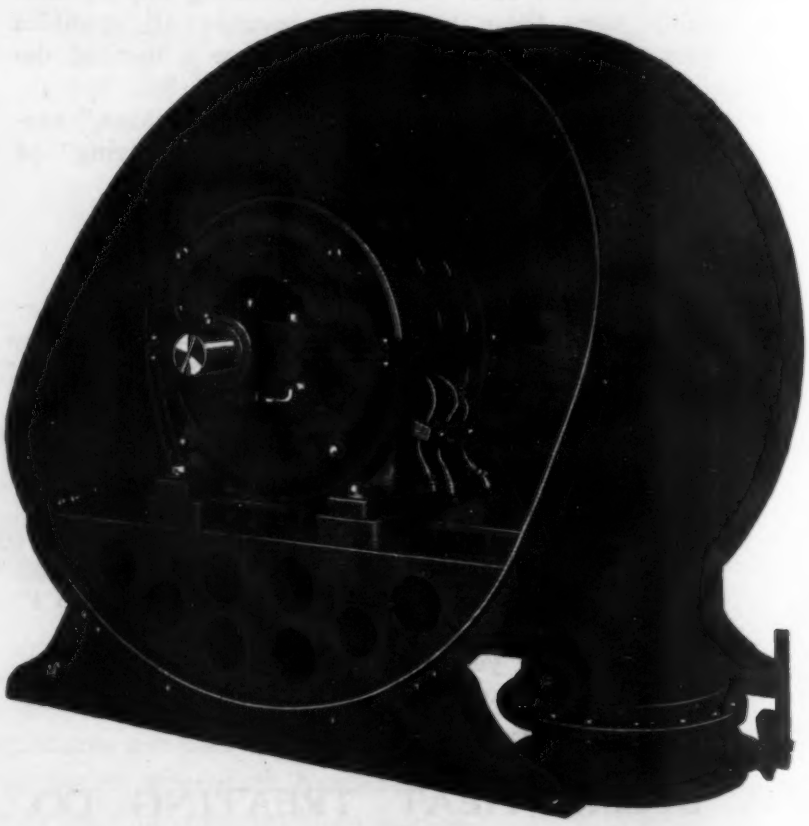
It has no contacts nor even close clearances, hence no chance for wear.

It is a direct connected, self-contained unit, hence no belts, gears or chains with their resultant losses and noises.

It gives constant pressure with no pulsations and no surging.

It operates at low velocity.

The current consumption inherently decreases in proportion to reduction of volume of air used, eliminating all auxiliary governors.



Motor End No. 1560 Turbo-Compressor

The Spencer Turbine Co.

HARTFORD, CONN.

Ask your furnace manufacturer for details

Over 5000 shops scattered throughout U.S. and Canada began todays work with tools made of

Red Cut Superior
HIGH SPEED STEEL

The Nationally Known and Recognized First Quality Steel

VANADIUM ALLOYS STEEL CO. ~ LATROBE, PA.

HY-TEN

PROGRESS

WHELCO

THE HIGH QUALITY AND UNIFORMITY OF HY-TEN ALLOY MACHINERY STEELS AND WHELCO TOOL STEELS HAVE BEEN IMPORTANT FACTORS IN THEIR CONTINUED SUCCESS. . . . . .

IN ADDITION TO CONSTANT IMPROVEMENT IN THE OLDER GRADES, WE ARE ALWAYS STUDYING AND DEVELOPING NEW COMPOSITIONS AS CONDITIONS REQUIRE. THIS PROGRESS IS REFLECTED IN EVER INCREASING SALES. . . . .

OUR STEELS ARE THUS ALWAYS KEPT ABREAST OF THE TIMES AND YOUR ADOPTION OF HY-TEN AND WHELCO INSURES CONSTANT IMPROVEMENT IN YOUR OWN PRODUCTS. . . . . .

WHEELOCK, LOVEJOY & CO., Inc.

CAMBRIDGE - NEW YORK - CLEVELAND - CHICAGO

ROCKWELL HARDNESS TESTERS

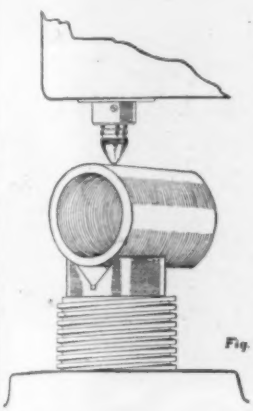


Fig. R2.

10/24/25

"WE are glad to note that the Rockwell Testing Machine is coming into increased use in other plants.

"We use this machine primarily for raw material inspection to insure that all our strip and tubing meets with our specifications as to hardness.

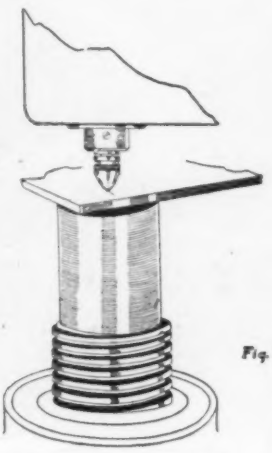


Fig. R3.

"We are very glad that we have purchased this machine."
(signed) Hollow Ball Co. Inc. by F. J. Lamb, Factory Supt.

WILSON-MAEULEN PYROMETERS

WHEN it comes to apparatus that you rely upon to do some important thing **automatically,** as you depend upon a pyrometer controller, then surely you need equipment of good design and showing good instrument work.

We originated the multiple unit control operated from a single standard motor for simplicity and robustness.

Each control unit is likewise designed for exceptional robustness and simplicity for your benefit.

WILSON-MAEULEN COMPANY INC

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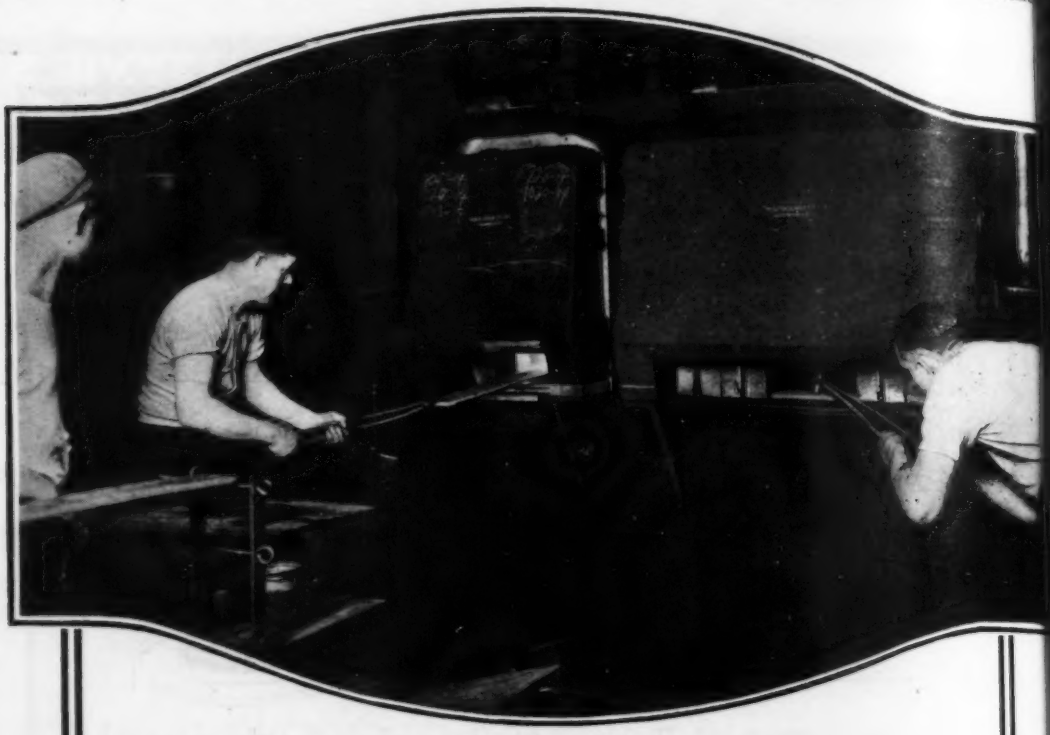

CARBOFRAX HEARTHS
GIVE AN INCREASED PRODUCTION

YOU get far more production out of a furnace equipped with a Carbofrax Hearth.
There are several reasons why.
In the first place you can load your burning chamber to capacity, for with a Carbofrax Hearth you get a uniform distribution of heat throughout the chamber.
Its remarkable heat conductivity takes care of that.
There is no "hot spot." You can load the chamber from door to back.
Because of its great, mechanical strength, a Carbofrax Hearth will permit your increasing the load without fear of the hearth sagging or buckling.
Then, too, you get an increased production because the Carbofrax Hearth stands up longer without softening, spalling or cracking. The need for frequent shut-downs for repairs is eliminated.

[GLAD TO HAVE YOU CONSULT WITH OUR SALES ENGINEERING DEPARTMENT]

CARBOFRAX
THE CARBORUNDUM REFRACTORY

Brick and Tile for Boiler and Furnace Settings; Muffles for Enameling Furnaces; Hearths for Heat-Treating Furnaces; Cements for all High Temperature Work

THE CARBORUNDUM COMPANY, PERTH AMBOY, N. J.

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Better Gears

with less-experienced help

The use of an electric furnace for heat treating results in an improved product. That this can be accomplished with inexperienced help, is not always realized, but the Stockbridge Machine Co., at Worcester, Mass. found it to be true.

Desired results from the G-E Electric Furnace are not dependent upon an operator's judgment —the Automatic Temperature Control does the thinking. And with Direct-Heat Units, uniformity of temperature throughout the furnace chamber is assured.

With this furnace, Stockbridge did its own carburizing for the first time. For this work the furnace is run continuously—3 heats a day being handled. A time switch starts and shuts it off, minimizing attendance.

Mr. Beeman, General Manager, when asked his opinion of this furnace said, "We are more than satisfied."

Improved working conditions invariably result in production economy. Electric heat —clean and easy to hold within its radius of usefulness—makes working conditions more agreeable. Industrial Heating Specialists located in every G-E sales office have complete information.

31-13C

GENERAL ELECTRIC

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VOLUME II

Fuels, Furnace Types and Furnace Equipment
Their Selection, and Influence upon
Furnace Operation

by W. TRINKS

Professor of Mechanical Engineering, Carnegie Institute of Technology

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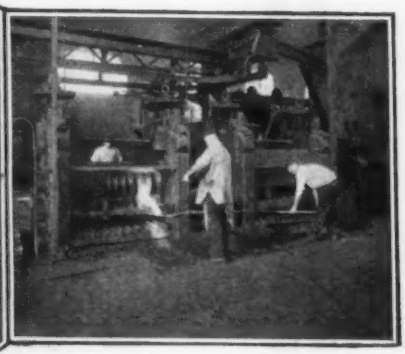
Section of Billet Grinding Department

3-Ton Electric Furnace



Billet Cogging Mill

BETHLEHEM Tool Steels are made under the most favorable conditions—conditions peculiar only to Bethlehem.

As a unit of a large steel organization with its great machine shops, rolling mills, bolt and nut plants, mines and railroads, the Tool Steel plant has at its command vast resources, extensive research laboratories and the benefit of a wealth of steel making knowledge with which to work.

Therefore, with a practical knowledge of what is required of various grades of Tool Steels, Bethlehem Tool Steels are scientifically developed to meet all conditions for which intended. They are put into actual service tests in the various departments where they are given severe usage. In these tests the steels must prove themselves fit for the particular use.

When you buy Bethlehem Tool Steels you buy steels of known performance and are protected by these service tests against inferior quality.

A Grade of Bethlehem Tool Steel for Every Purpose

Bethlehem Special High Speed Tool Steel
Bethlehem Finishing Tool Steel
Bethlehem XXX Special Tool Steel
Bethlehem Superior Tool Steel
Bethlehem XX Tool Steel
Bethlehem XCL Tool Steel
Bethlehem X Tool Steel
Bethlehem Tool Room Oil Hardening Tool Steel
Bethlehem Superior Hollow Drill Steel
Bethlehem X Hollow Drill Steel
Bethlehem Permanent Magnet Steels
Bethlehem No. 5 Nickel Steel 28.50-31.00%
Bethlehem No. 6 Nickel Steel 34.00-36.00%
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Sole Exporter of Our Commercial Products

BETHLEHEM

Yours—but not on your payroll

If the steel you use in your product is not of sufficient volume to warrant your maintaining a metallurgical staff for studying your individual steel requirements, remember that the Interstate staff of metallurgists is yours for constant counsel without obligation. These men are here for that purpose and their experience and knowledge will serve you well.

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Open Hearth Alloy Steel Ingots, Billets, Bars
Wire Rods, Wire, Nails, Rivets and Cut Tacks
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What Do You Know About the Heat Treatment of Steel?

A Booklet You Should Read

WHAT is the "decalescence" point in the heat treatment of steel? What is the "recalescence" point? Do you know the proper hardening temperature for high speed steel?

All of these points are discussed, and much other valuable detailed information is given, in a treatise entitled "The Cooling of Quenching Oil in the Heat Treatment of Steel," which has just been published by The Griscom-Russell Co., 97 West Street, New York. Any executive may obtain a copy free of charge by writing for it on his own or on his company's letterhead.

The first of the three principal operations in the heat treatment of steel is HARDENING, or quenching, and is the operation of quickly plunging steel, which has been heated in a furnace to a point above its critical temperature, in a cooling bath of brine, water or OIL.

The effect of quenching is to arrest or fix by rapid cooling certain changes in the internal structure of the steel which occur when the temperature passes above the critical range.

Modern practice provides for continuous rapid circulation of the quenching oil and for cooling external to the tanks. The engineering and designing staffs of The Griscom-Russell Company, after having devoted years of study and experiment to this problem, finally perfected the G-R Multiwhirl Cooler. Some of the advantages of this cooler are as follows:

(1) Patented Helical baffle—long smooth oil path—minimum pressure drop. (2) Tube bundle removeable—facilitating inspection and cleaning. (3) Tubes expanded into tube plates—no sweated joints. (4) Floating head construction - no expansions strains on tube joints. (5) Outside packed head—this construction eliminates any possible leakage of water into oil, through faulty packing. (6) Compactness of unit—this is permitted by the high rate of heat transfer secured in the Multiwhirl Cooler. (7) Installation in any position—the G-R Multiwhirl Cooler may be installed in any position with equal efficiency.

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If your industry touches the heat treatment of steel do not fail to write for a copy of the treatise.

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To Make Both

STAINLESS STEEL

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has developed laboratory precision on a production basis in selection of materials, in furnace technique, in forging, rolling, and in the exacting inspection of its products

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(1) The medal will be awarded to the author of the paper which shall be judged to be of the highest merit. All papers in order to be considered must be published originally in the TRANSACTIONS of the Society during the twelve months ending August 1st of the year in which the medal is awarded.

(2) The competition for the Henry Marion Howe Medal shall be open to all.

(3) The award shall be made by the Board of Directors.

(4) The award may be withheld at the discretion of the Board of Directors.

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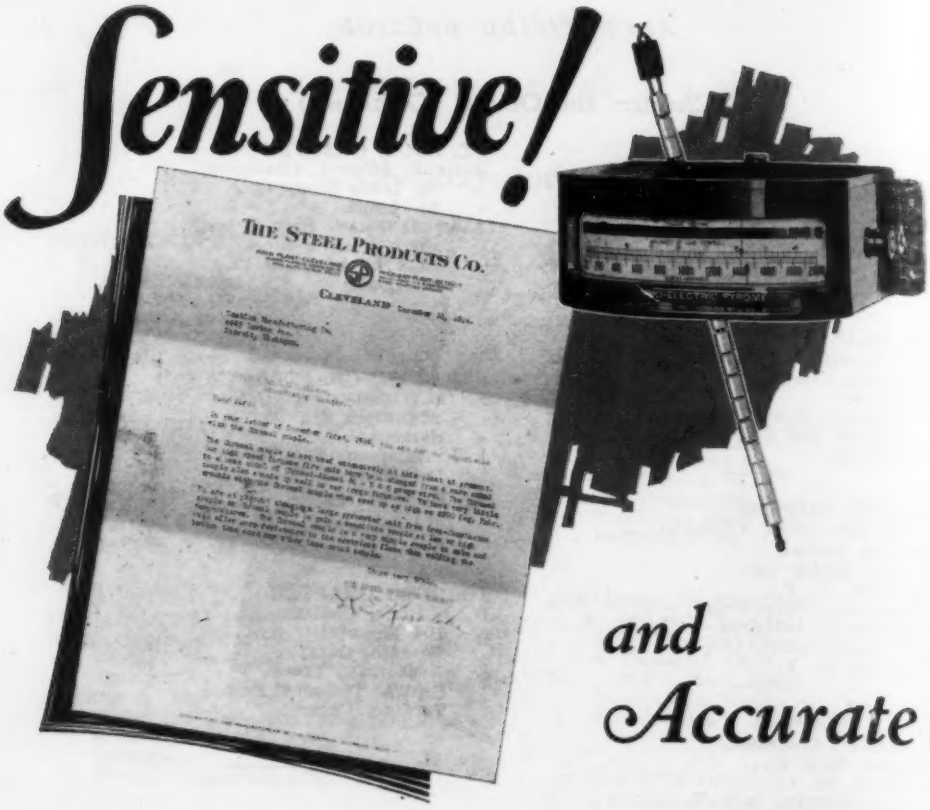

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FOR the past few years a competitive manufacturer of Carbonizing Boxes has had a large number of boxes fail, fall far short of their Guarantee. This manufacturer blames the CARBONIZING COMPOUND in a number of cases,—and has tried to get certain large manufacturers to change compounds, which, chemically and metallurgically are giving perfect satisfaction.

SUCH A POLICY IS UNFAIR TO THE COMPOUND MANUFACTURER

1. If this Alloy Manufacturer desires to criticize the products of several well known compound makers, this criticism should be made **before the Customer is sold** carbonizing boxes which won't stand up with his compound, instead of handed an alibi after he has bought the boxes.

2. If this Manufacturer's product is unfitted for use with Carbonizing Compounds used by from 20% to 40% of all users,—he should get wise and make boxes that will Stand the Gaff,—or not sell his boxes where he knows, or should know, they won't stand up.

3. If he does "Pull a Boner" and sell boxes to a concern whose practice is too stiff for them,—he should take his licking without whining,—and make adjustment with the customer,—FOR HE SHOULD HAVE INVESTIGATED THE USER'S CONDITIONS BEFORE RECOMMENDING HIS PRODUCT.

THERE IS NO HEAT TREAT ANYWHERE BUYING COMMERCIAL COMPOUNDS FROM ESTABLISHED MANUFACTURERS WHERE Q-ALLOY BOXES HAVE FAILED.

Once we sold some Boxes to a Cleveland concern which makes its own compound with a great excess (approximately 27%) of energizer, these boxes were eaten chemically and failed in six months. Other alloys failed in less time. WE MADE A CASH REBATE, **The other alloy manufacturers passed the buck.** This is a freak compound, tried and abandoned by several other companies. We know of no other concern using anything like it. **We had grounds to pass the buck, for the user didn't notify us until the boxes were too far gone to use,—but we took our Medicine.**

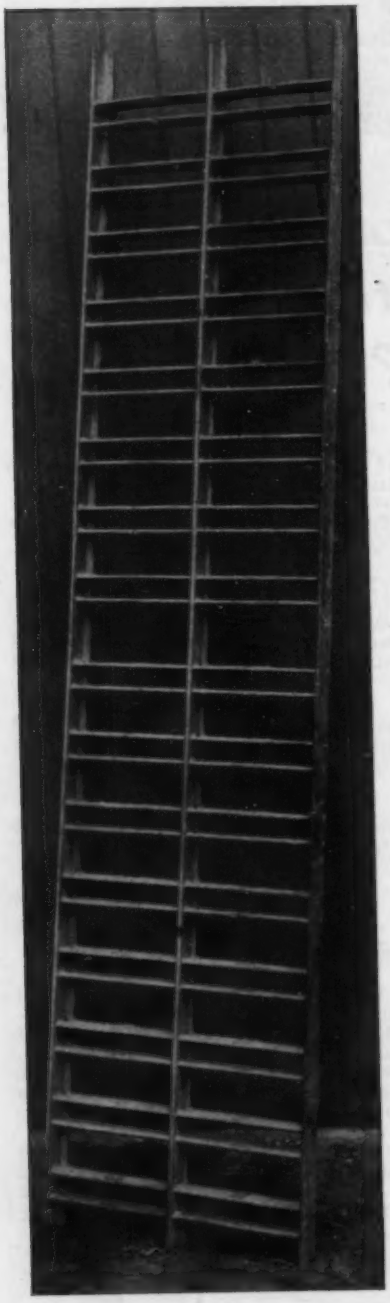
IF THE ALLOY MANUFACTURER YOU BOUGHT YOUR BOXES FROM STARTS TO KICK ABOUT YOUR COMPOUND AFTER HE HAS TAKEN YOUR MONEY,—MAKE HIM SETTLE,—AND—NEXT TIME BUY BOXES THAT WILL STAND UP,—MADE BY A CONCERN THAT WILL STAND BEHIND THEM. You guessed it, Q-Alloys.

Q-Alloy boxes are giving satisfaction with all standard Compounds, both "Sodium" and "Barium" Energized.

General Alloys Company

Holcroft Again

THE X-ite cast Element Rack, a vital part of the famous Holcrof Drawer Type Removable Heating Elements,—shown on the left, is far better rack than its predecessors. G. A. Co. Foundry Practice has mad possible the casting of this rack in one piece up t six feet long. Former racks were cast in tw pieces and welded together.

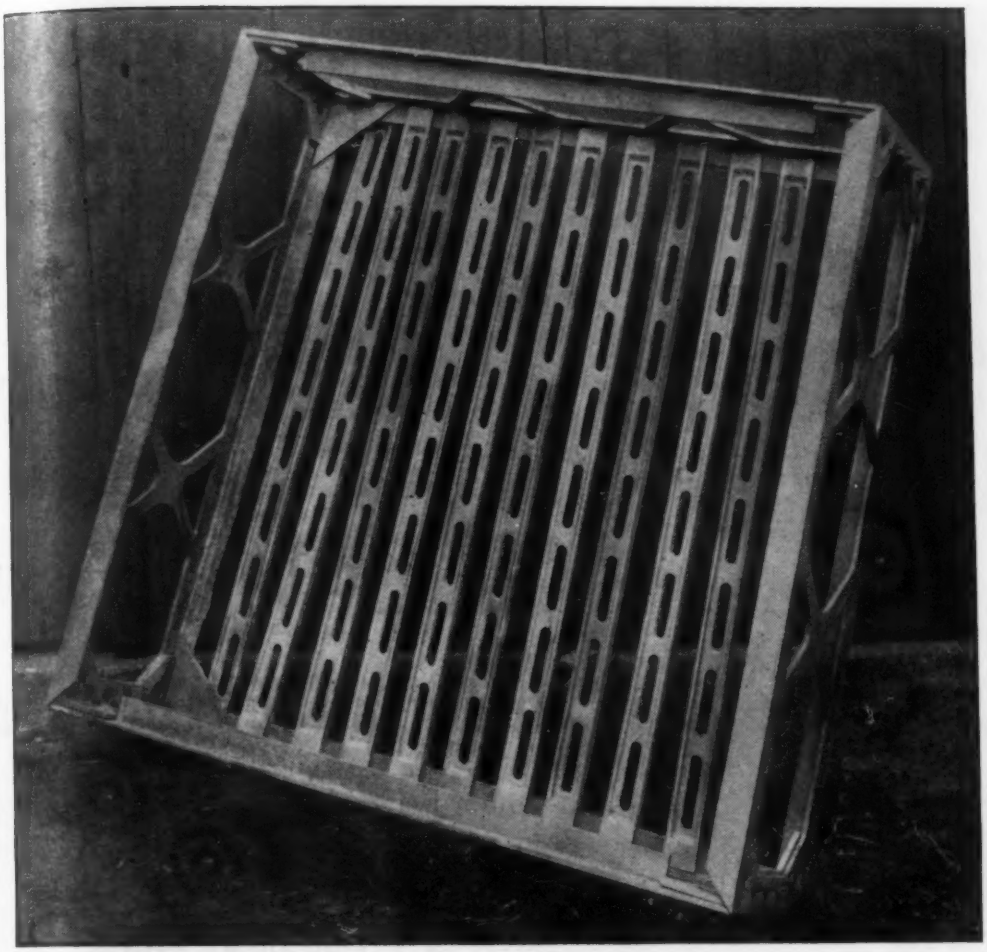


This Rack is made up of a total of over 75 ft. o ¼" X-ite in strip section cast in one piece. It i another example of the kind of castings the dub don't make,—and is one of hundreds of reason why hundreds of Customers have turned to u for castings after trying competitive products. On a recent Holcroft order we supplied 3200 cast ings of the same pattern, and turned them out a the rate of 700 per day. On another Holcrof order we received the print Friday evening worked two Pattern Makers all day Saturda and Sunday on a pattern for a five foot spide for a Rotary Hearth Furnace, and had the cast ings in Detroit Thursday Morning by packag car freight.

On another Holcroft order a solid carload of near ly a thousand castings from 31 different pattern was shipped as a unit, all ready for erection in th Customer's plant.

We have been giving the same class of casting and this typical Q-Alloy service to several oth leading furnace builders for several years. Th service is essential to them, for they have ere tion crews working on schedule and delays co money.

THE POINT OF THE ABOVE PARA GRAPHS IS: IF YOU SPECIFY Q-ALLO OR X-ite FURNACE PARTS YOUR FU NACES WILL BE ERECTED ON SCHEDULE. Better yet, the will run on production schedule for many years to come.



Electric Furnace Company

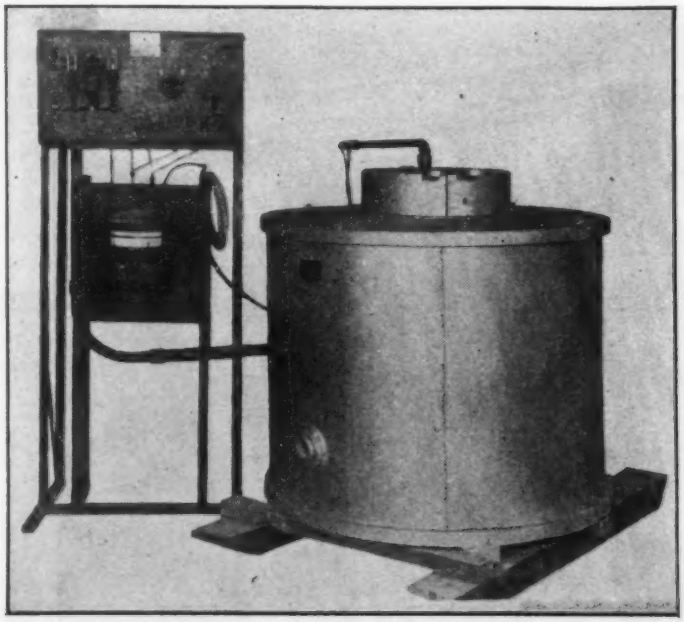
Some More

THIS ingenious design of the Electric Furnace Company makes possible a weight saving of approximately 76% over solid cast alloy containers. Engineering Brains,—Plus G. A. Co. Castings, made this possible. One would be lost without the other.

These castings fit together like a baby on a nipple. They can be Bolted, Welded, or Riveted with Q-Alloy Bolts, Rods, or Rivets. These baskets can be stacked, pushed or handled by any conventional method. They will stay put.

The dimensions of these baskets are 4 ft. x 4 ft. x 1 ft. and all the metal sections are ¼ in. Notice the clean-cut cored holes, the sharp corners and uniformity. A steel fabricating shop might well be proud of these baskets,—yet they are castings.

This kind of foundry work gives the word "Casting" a new meaning, and opens the way to the new era of Steel Treating Machinery.



SEVERAL Q-ALLOY CYANIDE POTS HAVE RUN OVER 10,000 HOURS

American Metallurgical Corporation

IN their Advertising in the November issue of TRANSACTIONS the American Metallurgical Corporation in advertising their Electric Cyanide Pot Furnaces made this Statement:

"Q-Alloy Pots have run in excess of 10,000 hours with no signs of deterioration."

This is a startling revelation, even to us, and we took pains to check the records involved ourselves. We found, for instance, that the Pratt & Whitney Company have been running their first American Met. Furnace with a Q-Alloy pot three years, and A. H. d'Arcambal, Chief Metallurgist, advises that the Q-Alloy pots in this furnace and his other American Met. Furnaces look "as good as new".

When you consider that these pots are only ONE HALF INCH THICK, uniform wall section, bottom and all, and that NO OTHER ½" ALLOY CYANIDE POT MADE BY A COMPETITOR EVER RAN 5000 hours,—You'll agree that Q-Alloy pots are far too good for you to do without them.

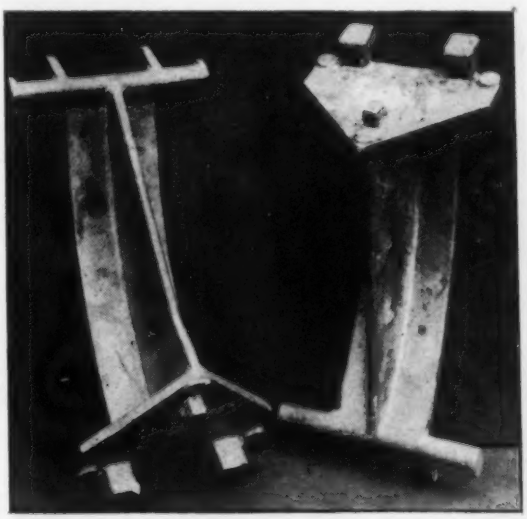
But we don't take all the credit for the 10,000 hours. The same pot might not last 1000 hours in old fashioned cyanide furnaces. The cost of this Modern, Efficient Furnace was saved in pot savings alone. How would you like to run your cyanide pots three years without a breakdown?

Hagan Progresses

WITH five Hagan orders going through the plant, we wondered which one to photograph for this issue. Most of these orders cover hearth plates for three giant Hagan Rotary Hearth Furnaces, and other standard castings,—so we picked out a queer one.

Take a look at the fine castings shown here, notice the unusual sections, and integral hinge pins,—then guess what they are.

Five years ago it would be almost impossible to run a picture of a furnace part that every heat treater wouldn't recognize, for the old types of furnaces have been familiar to three generations.

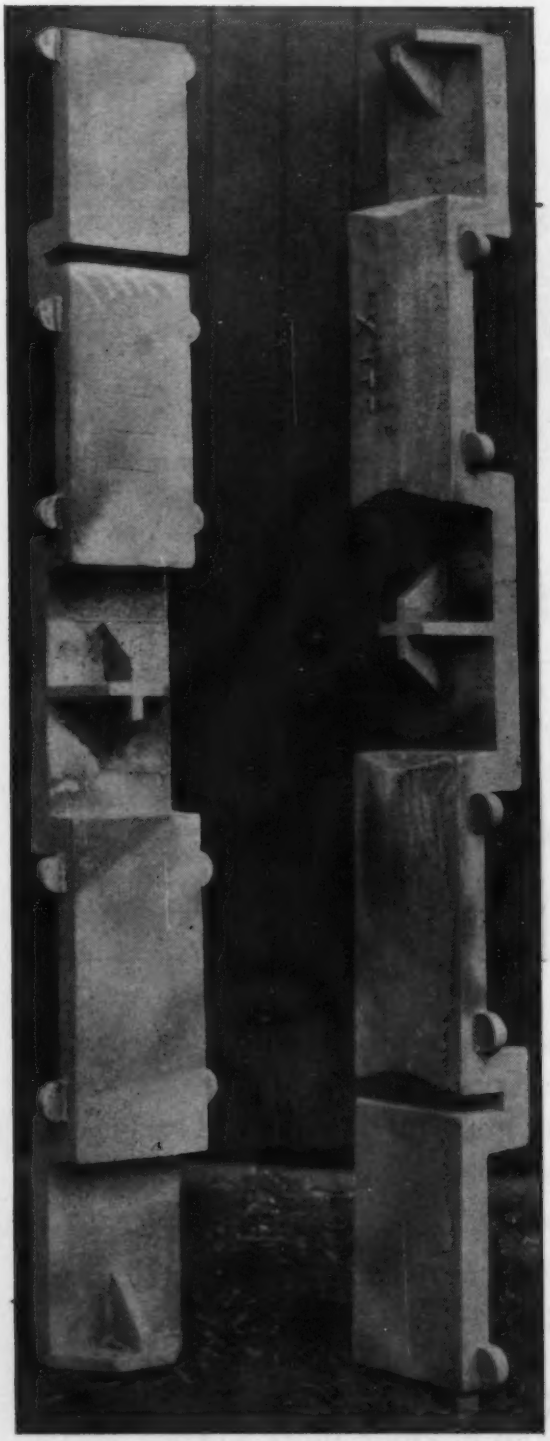


"Them days has gone forever,"—Furnace designers are now mixing brains with materials,—they are building furnaces that heattreat the work instead of heat the heattreat,—and Q-Alloys have been a vital factor in this development.

The George J. Hagan Company was the first Furnace Builder to conduct a Metallurgical and Physical investigation of Heat Resisting Alloys for Furnace Parts, and the first Furnace Builder to adopt Q-Alloys as a Standard Specification. Their judgment has been confirmed by the entire industry.

A College Professor at the Cleveland Show remarked: "These new type high efficiency furnaces are becoming Fashionable." "Fashionable, Hell," replied a Detroit Metallurgist, "they're absolutely essential to the modern Heat Treat, and," he continued, "the weak spot in most plants today is the Heat Treat, and the weakest spot in most Heat Treats is the Old Fashioned box type Furnace that sits and grunts, and averages 10% efficiency."

Anchoring to Brickwork



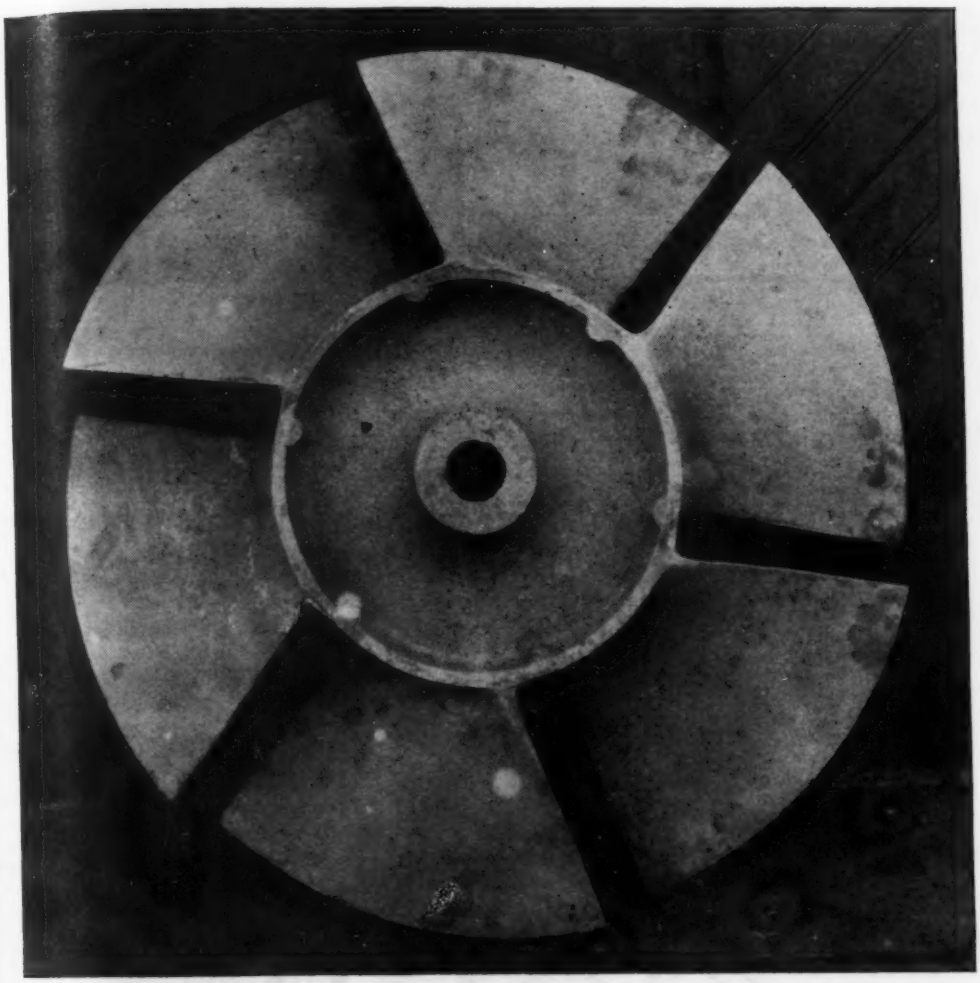
ANCHORING Alloy Hearth Plates to brick work was somewhat of a problem,—when the brick work was designed from Grandfather's drawings, and the alloy applied as an afterthought. Patching up an old design usually results in compromise.

The Modern furnace designer starts with the Customer's requirements, and builds a new furnace from the ground up, designing each component, Refractories, Insulation, and Alloy to function as a unit.

The X-ite Pier Cap hearth support shown here is a splendid example of modern design and G. A. Co. Foundry Practice. These Castings are cored out on the reverse side, and maximum metal section is ½".

The Chief Engineer of a large Company suggested to us: "Why don't you reprint all your Q-Alloy casting pictures as shown in the Box Bulletin, and publish them in Text Book form as a correspondence course in Foundry Practice for your contemporaries? They sure need it."

The Castings shown in these pages should furnish inspiration to the Engineer and Foundryman alike, for they represent a definite stage in the advance of the art, and are there a contribution to the entire industry, customer and competitor alike.



This Q-ALLOY Fan Turns 3200 R. P. M. At 2,000° F.

A WELL KNOWN Engineer figured out some time ago that if he only could make a fan of material to withstand the temperatures, he could circulate high temperature gases in open hearth furnaces and save several thousand dollars in fuel annually per furnace.

His dream came true with the development of this Q-Alloy fan, cast in static and dynamic balance, with blades ¼" in section, and a maximum operating temperature in excess of 2200° F.

This fan is designed to operate at 3200 R. P. M. at a normal temperature of 2000° F. It is another example of the way brains can be mixed with Q-Alloy to save dollars.

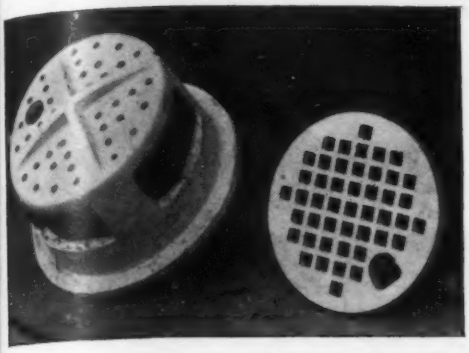
Keep your eye out for possible opportunities in your own plant to save time and money by mixing your brains with our alloys.

Q-ALLOYS

are

GOOD

ALLOYS



"SIEVES TO SAVE DOLLARS"

This would be a fitting title

Are dollars slipping thru your fingers?

GUESS what this is. It looks like some of those special Q-Alloy valve parts,—but it isn't. I'm batting this copy out on the eleventh hour in Hal Chase's Apt. in Cleveland and I don't know what the darn thing is myself, so I can't tell you. That's that.

This thing may be some kind of a sieve, if so it will save dollars that otherwise would slip through as waste, for undoubtedly Q-Alloy castings, in one form or another have saved more dollars that were slipping through the fingers of American Steel Treaters than all other Heat Resisting Alloys combined.

NEW SELF FLUXING Q-ALLOY WELDING ROD

Anybody can use it

NO more worries about getting good welds with green welders on Q-Alloy. Our new rod, recently developed with the aid of two of the world's greatest Laboratories, eliminates flux and insures a clean malleable weld.

Q-Alloy rods are the same analysis as Q-Alloy castings and have the same expansion and contraction. They can be depended upon for uniform results.

If you want to weld any competitive heat resisting alloy, and have the weld outlast the alloy, use Q-Alloy rods.

Q-ALLOY SELF FLUXING RODS ARE THE GREATEST CONTRIBUTION TO DATE TO THE ALLOY WELDING ART.

Q-ALLOYS
STAND UP UNDER FIRE

Q-ALLOYS

Most Economical and Efficient Materials

For CARBONIZING BOXES
ANNEALING BOXES
CYANIDE AND LEAD POTS
FURNACE PLATES
MUFFLES AND RACKS
TUBES AND RETORTS
CONVEYOR FURNACES
GLASS ROLLS AND DIES
ANY PARTS

operating between 1000° F. and 2200° F.

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How Republic Motor Trucks Are Protected

Every Republic Motor Truck crated for export is coated with NO-OX-ID. Shipment shown above is en route to Sydney, Australia.

Rust is inhibited. The surface is sealed. NO-OX-ID is applied easily by brushing, dipping or spraying. It is removed quickly with a rag when desired. Does not dry out, harden, crack or flake and does not "slip" at tropical temperatures. Immersion of Repubic Trucks in sea water has more than once proven that surfaces coated with NO-OX-ID are fully protected. Likewise, protection is given against the effects of sweating, exposure to weather, to acid fumes and other rust stimulating conditions.

What service can NO-OX-ID render you? Consultation invited —recommendations and demonstrations arranged gladly.

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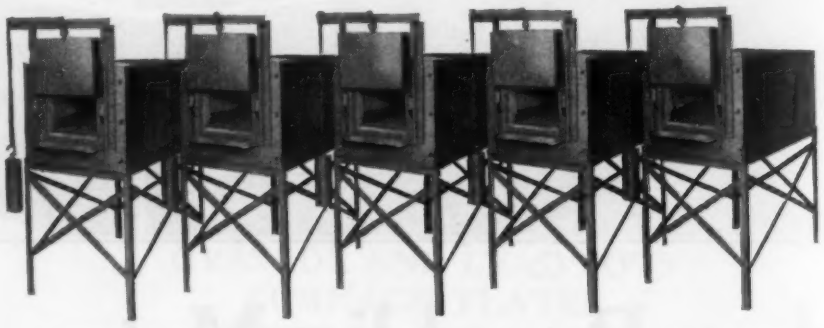
NO-OX-ID
IRON + OX = RUST
—TRADE MARK—
The Original Rust Preventive

HEVI DUTY

ELECTRIC FURNACES FOR YOUR TOOL ROOM



WE ARE pleased to announce our type **HD-136-R** Electric Tool Room Furnace, which we are building on a volume production basis, enabling us to give you the benefit of the consequent volume production price.

You will find in these furnaces the same high standards of materials and workmanship for which "HEVI-DUTY" has always stood.

A post card will bring specifications and operating economies.

HEVI DUTY ELECTRIC CO.

MILWAUKEE, WIS.

(Formerly Electric Heating Apparatus Co., Newark, N. J.)

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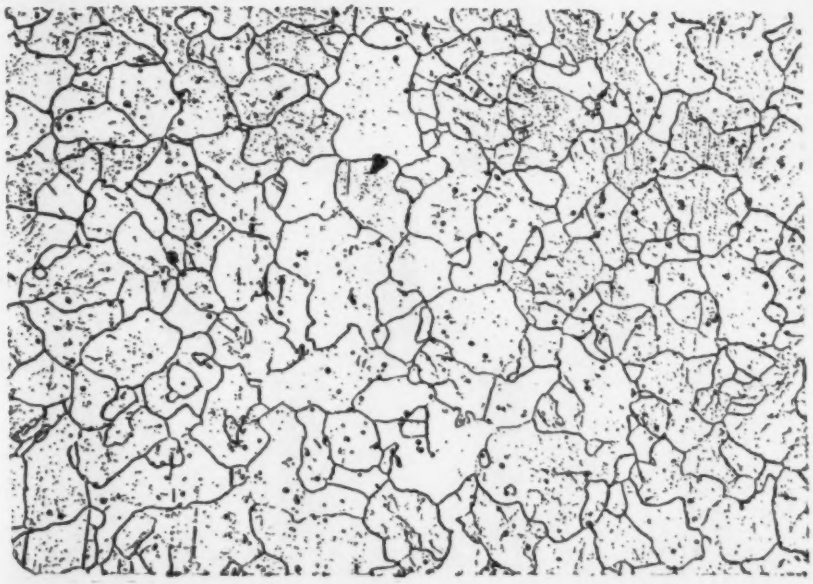

Are You Interested—

In the microstructure of commercially pure iron? This is one of the subjects discussed in "The Composition and Structure of Iron and Steel"—The third of a very interesting and practical series of articles being written for REPUBLIC FLOW METERS COMPANY thru the courtesy of Professor H. M. Boylston, noted authority on the subject of "Steel and its Heat Treatment."

By simply mailing the coupon below, the first three of these articles will be forwarded to you, others to follow at approximate monthly intervals. There is no obligation whatever as these discussions are being written for Republic in the interest of greater efficiency in the Heat Treating field.

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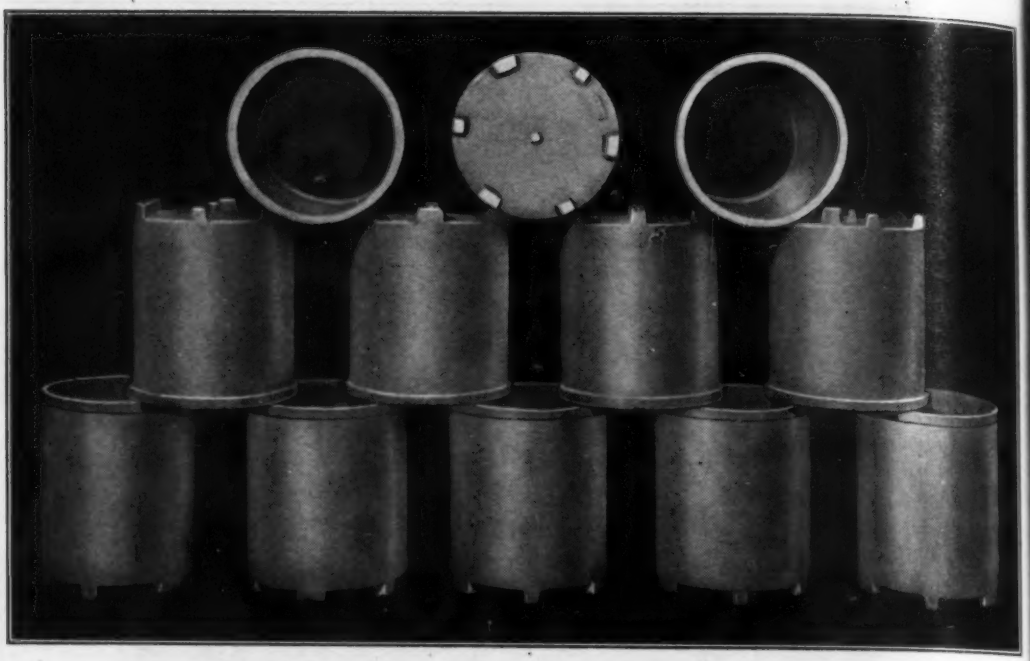

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ECONOMICAL AND EFFICIENT FOR

CARBONIZING BOXES and COVERS
ANNEALING BOXES
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CONVEYOR PARTS
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"Where there is ***HEAT*** use SWEDISH NICKEL ALLOY"

ANALYSIS: Nickel 62 to 65% Chromium 15%

When answering advertisements please mention "Transactions"

Swedish Alloy Steel Carbonizing Boxes

Made of a high grade cast steel, these special alloy steel boxes and covers will give long service and lower your heat treat costs. Hundreds of heat treat plants are equipped with these boxes. The original investment is low and the number of hours' service obtained greater than those obtained from ordinary steel boxes.

Cyanide and Lead Pots

All SWEDISH POTS are made of a high grade CRUCIBLE STEEL. The dense, homogeneous structure of the steel gives maximum protection against the action of the lead or cyanide as well as to the action of the flame.

Patterns

At all times we have at our plant the latest designs in pots and boxes. Designed for long life with minimum wall sections and non-warping and non-cracking features.

SWEDISH CRUCIBLE STEEL CO.

DETROIT, MICHIGAN

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Made to Sell for a Purpose—Not a Price

Our experience of over 50 years in the manufacture of Steel Specialties guarantees you the Best Tool Steels that can be made.

We can offer excellent service from our Bar Steel Warehouses, which are well stocked with the standard and many of the odd sizes so often needed. We have a proven Tool Steel for every purpose. A letter or wire today will have the steel in your shop or in transit tomorrow.

A 32-Page Pamphlet just from the press gives useful hints on the handling of Carbon Tool Steels, as well as the proper grades for each purpose. Write for it.

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Bob McDonogh, in a "Miller Special," crossing the finish line, first in a field of fifteen in the Altoona 250-mile race.

McDonogh Wins!

DRIVING a "Miller Special" at a pace of 118 miles an hour for two hours, six minutes and fifty-four seconds, without a single stop, Bob McDonogh won the 250-mile automobile race at the Altoona Speedway, Altoona, Pennsylvania.

Miller Engine Works, Los Angeles California, (who built McDonogh's car, and thirteen other cars entered in the Altoona Race) realized the need for steel that combines strength, toughness and dependability with light weight. Chrome-Vanadium Steel was selected for:

Front Axle Ends	Valve Tappet Cups
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Whatever your steel uses or problems, if you are seeking stronger steels, lighter in weight, yet tough and dependable, there is a Vanadium Steel that will meet your requirements. If you will give us an outline of your steel requirements, our Metallurgists will be glad to give you their recommendations.

Fourteen of the fifteen contestants in the Altoona Race drove cars made by Miller Engine Works, 2652 Long Beach Avenue, Los Angeles, California. These cars were piloted by:

Norman Batten
Fred Comer
Earl Cooper
Earl Devore
Leon Duray
Frank Elliott
Harry Hartz
Ralph Hepburn
Benny Hill
Jimmy Hill
Bob McDonogh
Phil Shaffer
Doc Shattuck
Jerry Wonderlich

The first seven to finish—respectively, Bob McDonogh, Harry Hartz, Earl Cooper, Fred Comer, Leon Duray, Norman Batten and Phil Shaffer—drove Miller-built cars.

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Covers heat measuring and hardness testing instruments, various modern appliances, and the installation of up-to-date systems. Intelligent study of its contents will lead to the broader knowledge of heat-treating methods which is now required of the man actually doing the work.

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The NU-TYPE is the most beautiful and artistic pocket pencil on the market. In construction, in artistic finish, and design, in its sturdy wearing qualities it endears itself to its users. It is a "different" pencil, and a better pencil.

The barrel is made of light, hard, enduring rubber composition which takes a very handsome finish. The rubber barrel is, in turn, reinforced with a metal tube which, by its special design, insures a splendid combination of strength and lightness.

A common defect in other pencils of this type is the ease with which the leads break in feeding through the tip. This defect is remedied by a specially constructed tip and by the dual gripping action on the lead.

NU-TYPE is known as "The Panel Pencil." The panels, clips, nuts, as well as the tips and caps, are made of 14k gold filled. These panels are attached to the pencil, just above the clip, a patented feature, and are engraved with the A. S. S. T. emblem.

PRICE POST PAID

No. 150—Octagon Barrel, 5¼", Panel lock and A. S. S. T. clip, 14k Gold Filled..... $3.25

American Society for Steel Treating

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OVER *three decades* of successful operation in the manufacture of Oil Burners and Industrial Furnaces is the result of soundly engineered products of quality.

Satisfied users of our equipment have been responsible for our success.

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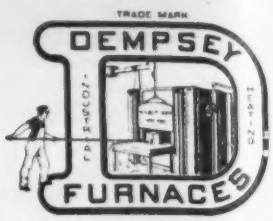

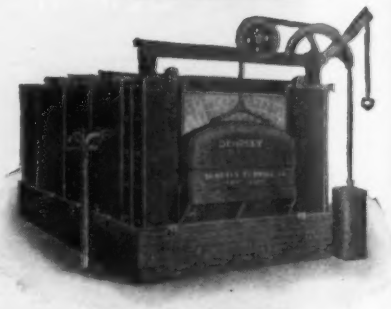

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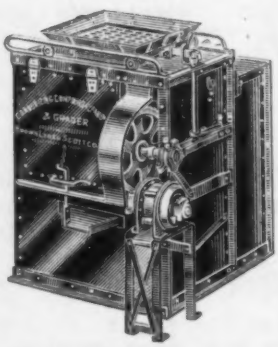

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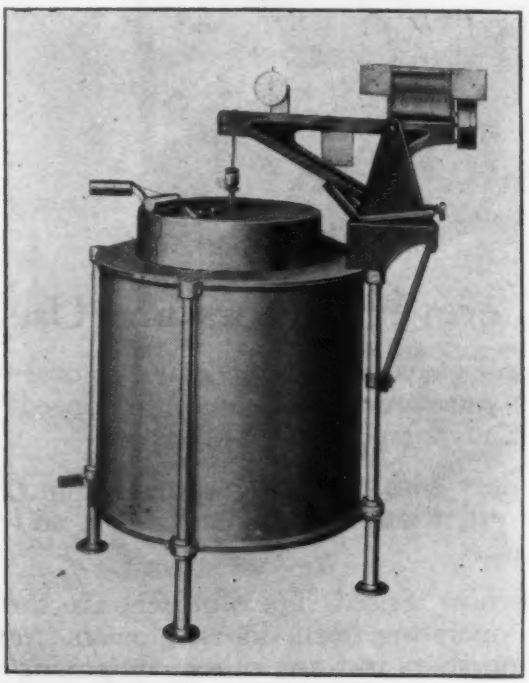

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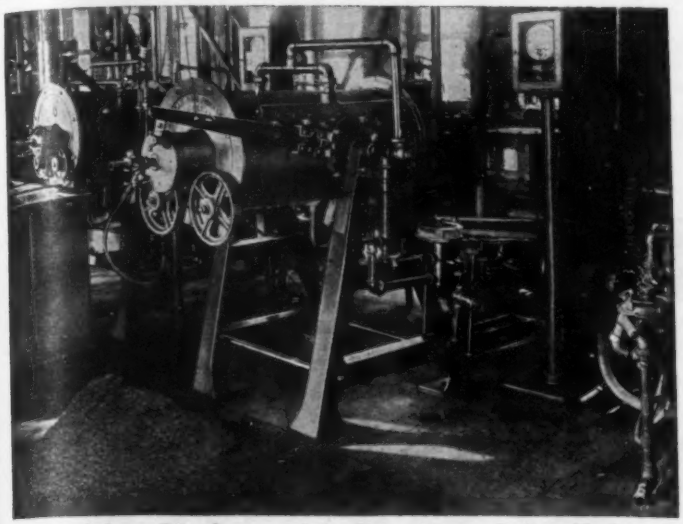

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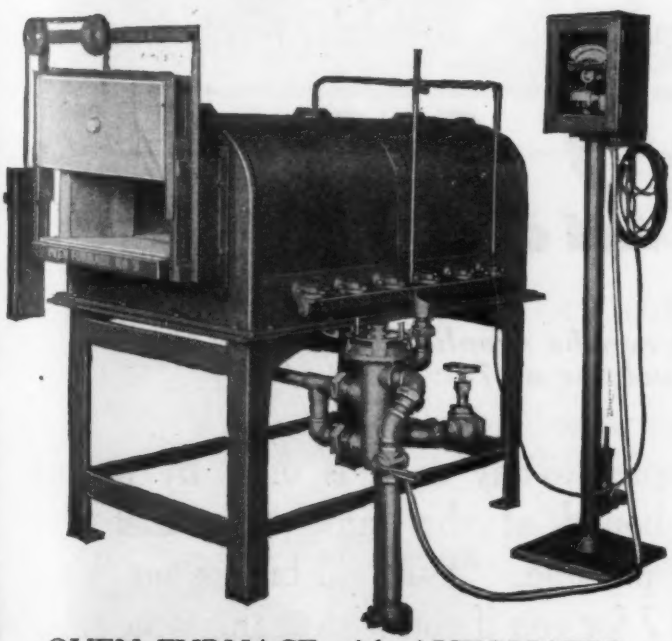

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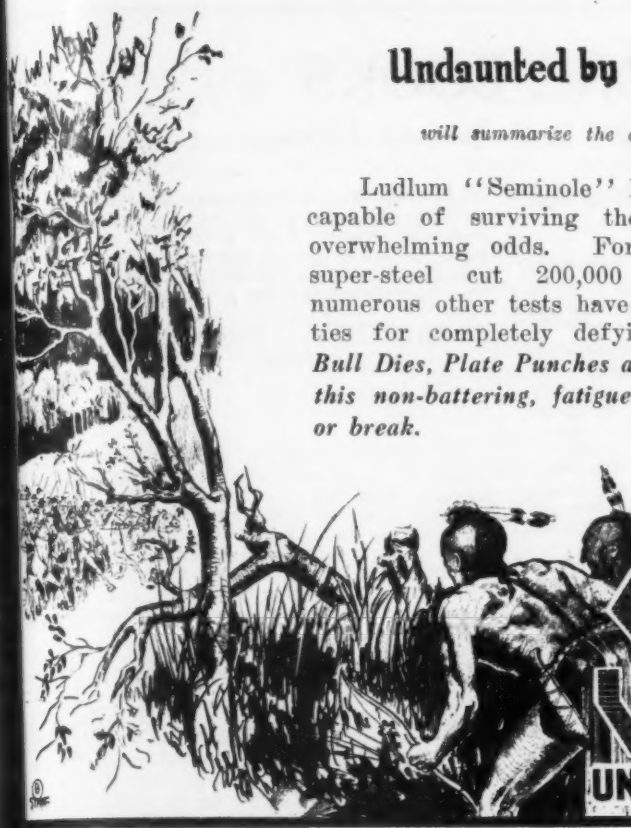

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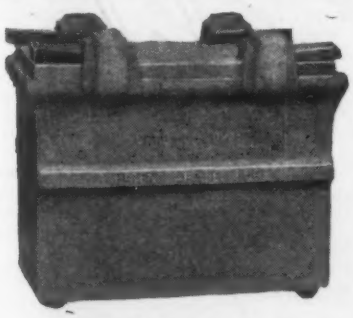

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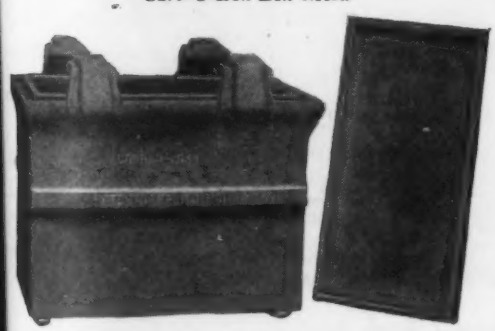

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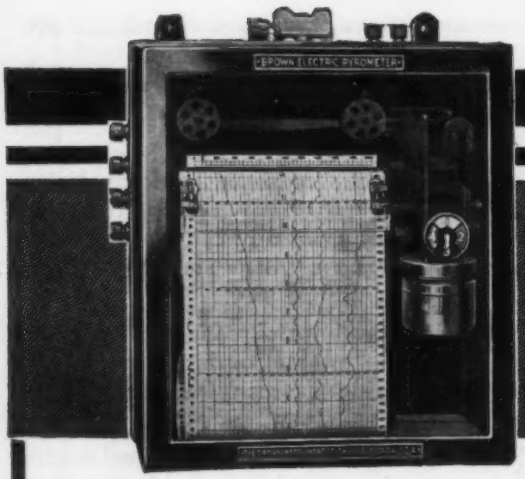

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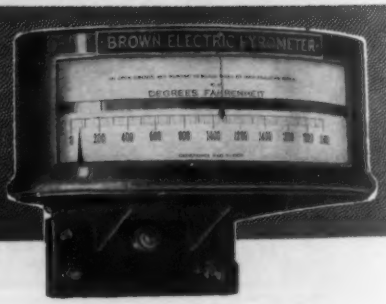

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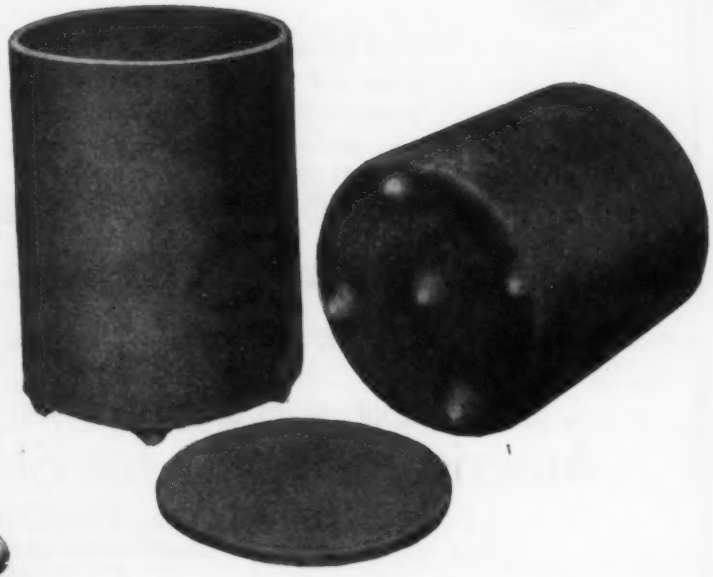

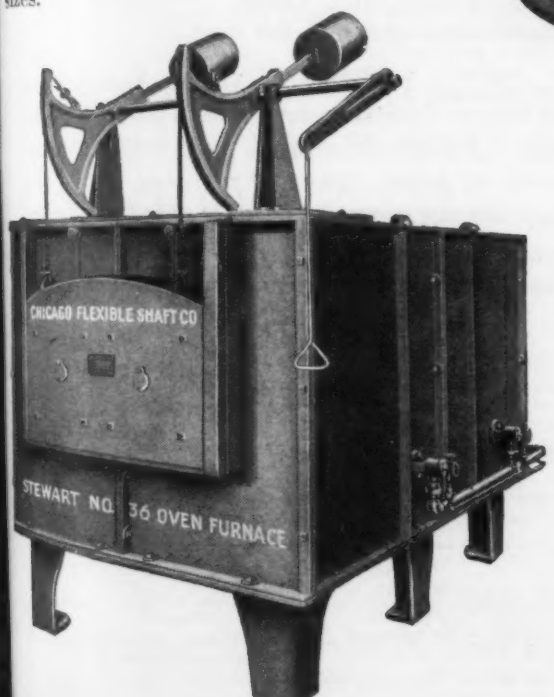

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Application for Membership in the American Society for Steel Treating

4600 Prospect Ave., Cleveland, Ohio

(See opposite page for Classification and rate for dues.)

I hereby make application for (*Member Junior / Associate Sustaining*) *membership in the Society, and agree, if elected, that I will be governed by the Constitution, By-Laws and Rules of the Society as long as I continue a member. I furthermore agree to promote the objects of the Society so far as it shall be in my power. $5.00 of my dues is for one year's subscription to The Transactions of the American Society for Steel Treating.*

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American Society for Steel Treating

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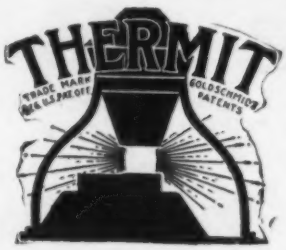

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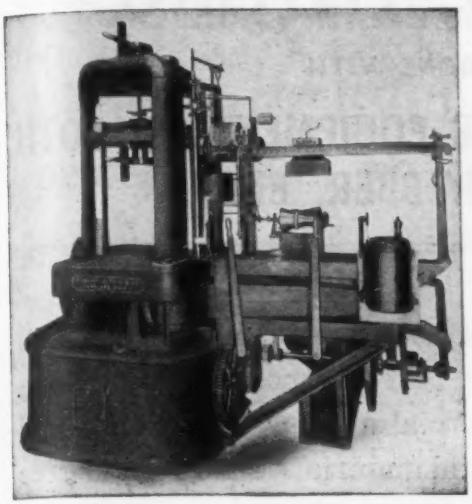

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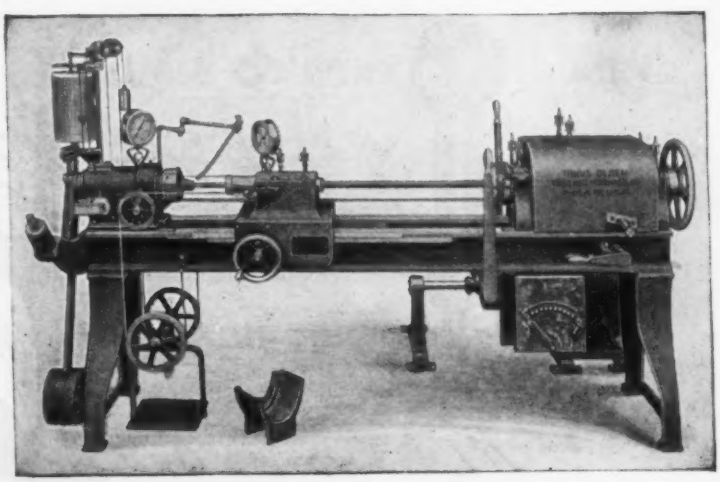

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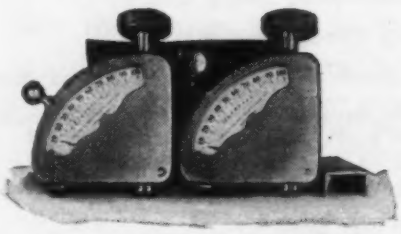

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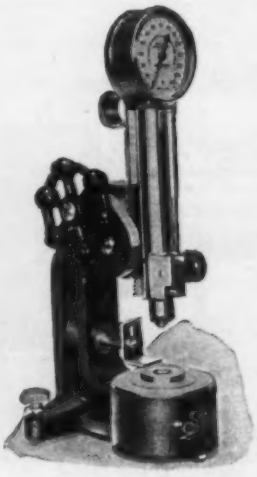

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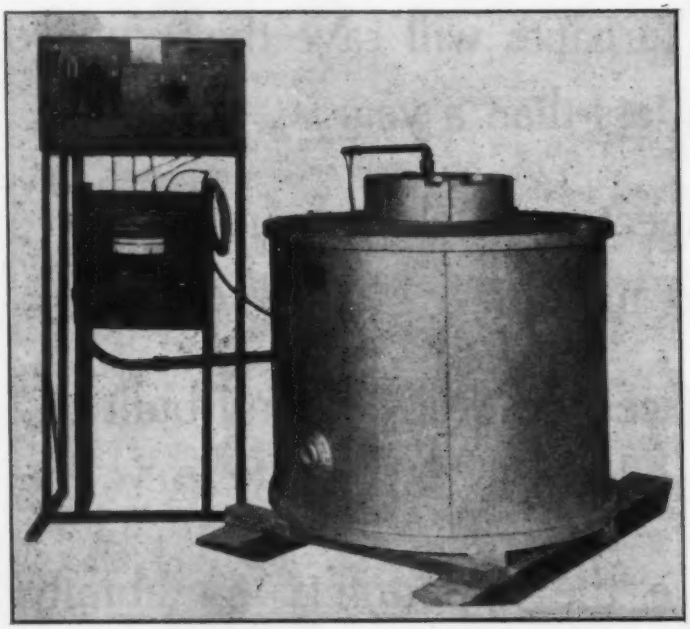

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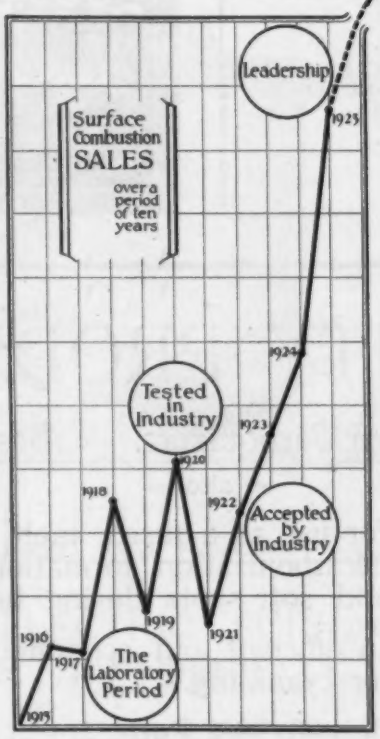

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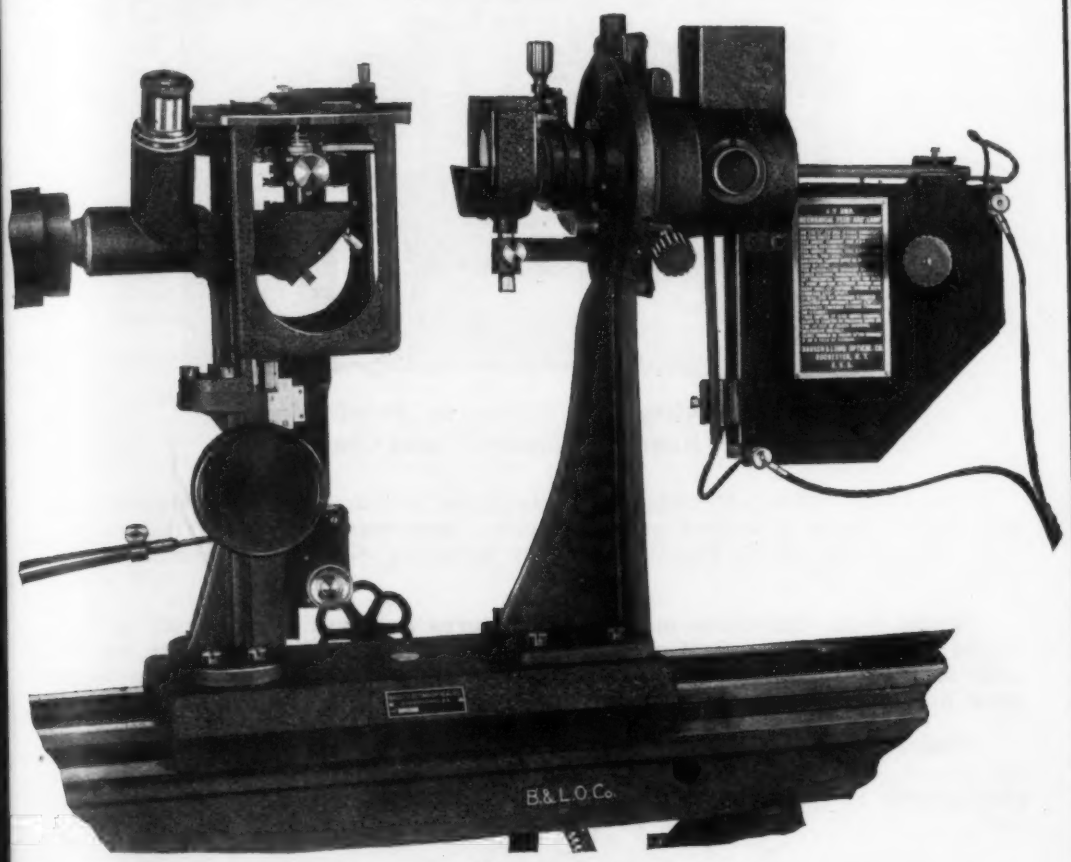

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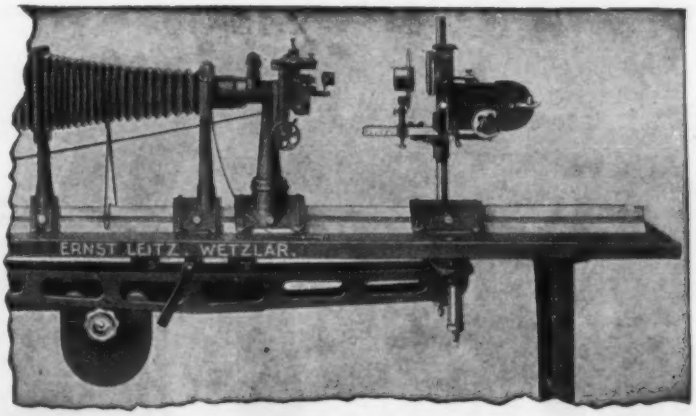

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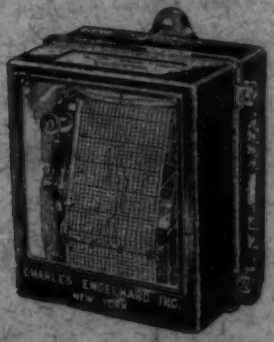

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